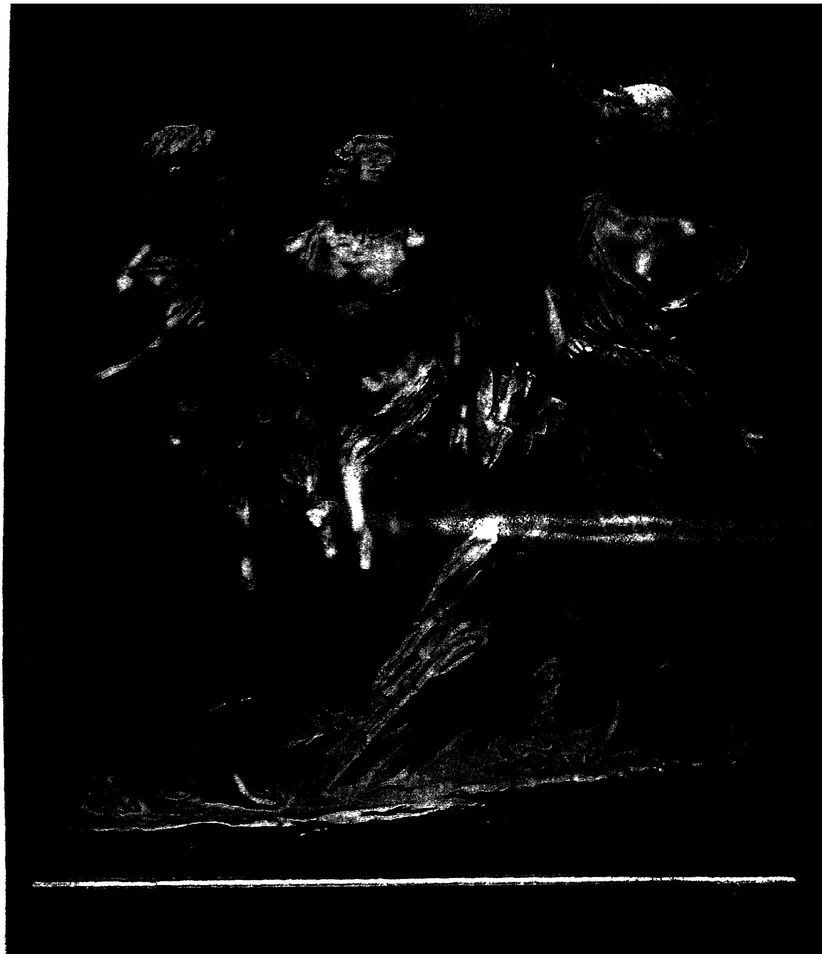

A LEGEND OF METALLURGY.

"THE GODDESS OF THE POLE STAR, DESCENDING FROM THE STARRY FIRMAMENT BECAME ENAMOURED OF A MORTAL, SIDÉRITE, BUT HE, LOVING NONE BUT HIS BROTHER, SIDÈRE, REPULSED HER. IN HER WRATH SHE TRANSFORMED THE DEVOTED BROTHERS, ONE INTO LOAD-STONE AND THE OTHER INTO IRON."

THIS BRONZE GROUP WAS PREPARED FOR THE WRITER OF THIS WORK BY THE SCULPTOR, MR. FREDERICK J. HALNON, AND WAS EXHIBITED AT THE ROYAL ACADEMY, LONDON, 1923.

METALLURGY

AND ITS INFLUENCE ON MODERN PROGRESS

WITH A SURVEY OF EDUCATION AND RESEARCH

BY

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PREFACE

In the preparation of this book it has been the author's aim to outline the rise of modern science and then to deal at greater length with various aspects of the work with which he has been particularly associated. Part I of the book is devoted to some of the pioneers to whom science in general and metallurgy in particular is so much indebted. Though necessarily incomplete, the information presented will, it is hoped, be found of interest and serve its purpose in paying tribute to some of the more notable early workers, whilst inducing readers—specially the younger men—to continue elsewhere the study of those who laid the foundations of modern science.

The next section of the book—Part II, Metallurgy—is devoted mainly to a consideration of the rise and importance of alloy steels, a subject with which the author has been most intimately concerned for nearly half a century. Much information is included regarding modern alloy steels and their applications and, though the indication which has been given of the industrial applications of alloy steels is necessarily incomplete, the author trusts that it will serve to demonstrate that we are passing out of the age of iron and simple steel, and that we have advanced into an era which may justly be termed an age of alloy steels for, without the use of such steels, it is certain that modern civilisation could not be carried on. It has been demonstrated that this advance represents not merely one with regard to special and comparatively small applications, but that alloy steels find uses, as in the case of manganese and other special steels, for large tonnage requirements, thus providing employment for many work-people.

It is impossible to predict the extent to which the use of alloy steels may develop and become of still further importance to the world. Research in this direction is showing that the possibilities of alloy steels are as yet exploited very incompletely;

the total field is of enormous extent, and by far the greater part of it is still unexplored.

The subject of fuel economy, now of such national and, indeed, world-wide importance, is one which has received much attention in the research laboratories and works of the author's firm. A general survey of the field, with detailed notes upon certain aspects of the subject, form Part III of this volume.

In many respects Part IV, dealing with education and research, is the most important in the book, for it emphasises the value of research work and reviews the methods and facilities now available for education and research. Tribute is paid to the invaluable work done by the great scientific societies of this country, and a special plea is made for federation of scientific and industrial interests. Along these lines lie our hopes for continued and increased prosperity and development as indicated in the concluding section, Part V, of the book.

When dealing with so vast a field much more might have been said, but for the limitations of space, and in offering this volume, which has had to be prepared amidst the innumerable distractions of busy and anxious times, the author asks that it may be regarded as an incentive to younger men, and as some measure of grateful recognition for the assistance which he has received during so many years, not only from the members of his own staff, but also from many other scientific and practical men at home, on the Continent, and in America. To those who are mentioned in this book, as well as to those who have been omitted inadvertently or by reason of space restrictions, the author expresses heartfelt indebtedness.

R. A. HADFIELD.

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PART IV. EDUCATION AND RESEARCH

Wisdom of the Ages.

"*I speak of that learning which makes us acquainted with the boundless extent of nature and the universe, and which even while we remain in this world, discovers to us both heaven, earth and sea.*"—Cicero (106–43 B.C.).

"*It seems to me that those sciences are vain and full of errors which are not born of the true knowledge which is the mother of certitude and which do not lead to the further establishment of fact.*"

Leonardo da Vinci (1452–1519).

"*No pleasure is comparable to the standing upon the vantage ground of truth.*"—Francis Bacon (1561–1626).

"*I call a complete and generous education that which fits a man to perform justly, skilfully, and magnanimously all the offices, both private and public, of Peace and War. . . . I shall detain you no longer in the demonstration of what we should not do, but straight conduct you to a hillside, where I will point you out the right path of a virtuous and noble education; laborious indeed at the first ascent but else so smooth, so green, so full of goodly prospect and melodious sounds on every side that the harp of Orpheus was not more charming . . . Be enflamed with the study of learning, the admiration of virtue, and stirred up with high hopes of living to be brave men and worthy patriots, dear to God, and famous to all ages.*"

John Milton in his "Tractate of Education" (1644).

"*Though all the winds of doctrine were let loose to play upon the earth, so Truth be in the field, we do ingloriously, by licensing and prohibiting, to misdoubt her strength. Let her and Falsehood grapple; who ever knew Truth put to the worse in a free and open encounter.*"

John Milton in his "Areopagitica" (1644).

CHAPTER I

THE BIRTH OF SCIENCE.

The Value of an Historical Survey.—The rise of metallurgy to its present eminence has been particularly rapid during the past fifty years but, prior to that, a considerable amount of knowledge—concerning the art rather than the science of metallurgy—had been accumulated slowly during a period of many centuries. Whilst, therefore, the main purpose of this book is to describe some of the important metallurgical developments of the past half-century and their effects on modern progress, no excuse need be offered for making a preliminary retrospect of early science in general and metallurgy in particular. There is much to be learned from such a study, for a correct conception of the living past is a guide and help to us to-day. Even so far back as B.C. 300 the philosopher Publius Syrus said: "Each present day is the scholar of yesterday."

Wherever possible the author has always tried to do full justice to the workers of the past, for it is largely from their wise prevision that we are to-day benefiting so largely. This policy is supported by Mr. C. Spiller in his valuable book, "A New System of Scientific Procedure," wherein he states that it would be a grave and unpardonable error to suppose that every invention and discovery of note dates from the rise or era of modern science. Long before that era man had invented language, alphabets, the arithmetical notation now in use, also customs, manners, morals, religions, and laws; domesticated diverse animals; developed the cereals, vegetables, and fruits, and discovered the use and safe production of fire; extracted, utilised, and mixed various metals; introduced the axe, the knife, the saw, the plough, the wheel, glass, mirror, sails, bricks, windmill and watermill, the calendar, the compass, spectacles, clocks, and scores of other inventions and discoveries of far-reaching significance; built magnificent roads, waterways,

carriages, ships, and temples; produced unsurpassed works of art, and developed man's sense of the beautiful; and laid the foundations of mathematics, astronomy, logic, and medicine, besides those of poetry, the drama, and literature generally.

Except for the purposes of geological, ethnological, and similar studies, the history of Great Britain as we know it to-day may be said to have commenced with the Norman Conquest in 1066. Soon thereafter learning began to take its rise in this country, and Oxford became one of the most important cities in the kingdom. By its association with Roger Bacon, Oxford has a special claim to notice in any account of the rise of science in this country. It is specially interesting to note the long period of stagnation which followed Bacon's work, and the sudden general awakening which occurred in all fields of knowledge during the 16th and 17th centuries. In this and the following chapter there is given a general perspective view, necessarily far from complete, of some of the steps by which science has reached its present eminence. Many of the workers and discoveries concerned are dealt with more fully in later chapters, but in selecting from the roll of the past centuries a few names for special mention in these introductory notes, limitations of space make it impossible to deal with all those who have contributed directly to the prestige of our country and to the advancement of science in general including metallurgy.

Early Science in Oxford.—In the thirteenth century, says Mr. R. T. Gunther in his admirable book on "Early Science in Oxford," the seeds of Arabian learning began to germinate in Europe among men of western race. The science of the Moors as in Spain had brought them European reputation: Emperors and Kings became their pupils and patrons. Natural science in the west began to put forth the first shoots of the tree that has grown so mighty.

In the course of his Presidential Address to the Classical Association at Oxford, on May 16th, 1919, the author's friend, the late Sir William Osler, F.R.S., referred to a loan exhibition of early scientific instruments and MSS. arranged for the occasion; he said:

> "A series of quadrants and astrolabes show how Arabian instruments, themselves retaining much of the older Greek models, have translated Alexandrian science into the Western world. Some were constructed for the latitude of Oxford, and one was associated with our astronomer-poet Chaucer.

"For the first time the instruments and works of the early members of the Merton School of astronomer-physicians have been brought together. They belong to a group of men of the fourteenth century—Reed, Aschenden, Simon Bredon, Merle, Richard of Wallingford, and others—whose labours made Oxford the leading scientific University of the world.

"Little remains of the scientific apparatus of the early period of the Royal Society, but through the kindness of the Dean and Governing body of Christ Church, the entire contents of the cabinet of philosophical apparatus of the Earl of Orrery, who flourished some thirty years after the foundation of the Society, is on exhibit, and the actual astronomical model, the 'Orrery,' made for him and called after his name."

Among other notable exhibits there were:

(1) A series of astronomical volvelles in manuscripts and printed books.

(2) The printed evidence that Leonard Digges of University College was the inventor of the telescope many years before Galileo.

(3) The mathematical work of Robert Recorde of All Souls College, in which he suggested the St. Andrew's Cross as the sign of multiplication, and used the symbols +, —, =.

(4) The earliest known slide-rule in a circular form, recently discovered in St. John's College.

(5) The early vellum and wooden telescopes of the Orrery Collection.

(6) An original Marshall microscope.

(7) Early surveying instruments, including the great quadrate of Schissler.

Roger Bacon (1214–1292).—Amongst the most eminent members of Merton College at that time, and specially distinguished by the fact that he was literally centuries ahead of his time in regard to scientific principles, there was Roger Bacon who, as a Franciscan, had to live in a Friary and not in the College itself. One of his collaborators must have been Richard Wallingford, who is entered on the Bursar Roll of the College as a maker of astronomical instruments.

In view of the fact that the foundation of scientific education in Oxford, indeed in this country generally, is bound up with the history of Roger Bacon, whose study of science in those early times was of the highest importance, no apology is needed for dealing at some length with his career.

Roger Bacon was born in 1214, and his life almost spanned the thirteenth century. His learning gained for him the title of Doctor Mirabilis from his brother-Franciscans.

From Oxford, where he studied under Edmund of Abingdon, to whom he owed his introduction to the works of Aristotle,

he passed to the University of Paris, where his whole heritage was spent in costly studies and experiments.

He finally returned to Oxford as a teacher, working there very strenuously. The pride with which he referred to the satisfactory development of his system of instruction was further justified by the results of the wide extension which he gave to scientific teaching, claiming, for example, that "The Science of Optics has not hitherto been lectured upon at Paris or elsewhere amongst the Latins, save twice at Oxford."

Such was the state of optical knowledge when he returned from his travels and proved to posterity how fruitful was his "Ratio inveniendi." In the Opus Majus dedicated to Pope Clement IV, c. 1265, he sketched out the properties of convex lenses in a more masterly way than any of his predecessors. Moreover, certain passages in his book appear to indicate that he knew the principle of the telescope.

To show how near the truth Roger Bacon had arrived, and this was in the thirteenth century, he wrote the following:

> "Glasses or diaphanous bodies may be so formed that the most remote objects may appear just at hand, and the contrary, so that we may read the smallest letters at an incredible distance, and may number things, though never so small, and may make the stars also appear as near as we please."

Mr. R. T. Gunther says, in the above-mentioned book, that undoubtedly Roger Bacon was the first person to publish his belief that small objects could be magnified, and distant objects brought near by means of single lenses and combinations of lenses, and that these effects were produced by enlarging, by means of refraction, the visual angles under which these objects were seen. Mr. Gunther points out that whilst the pathetic epitaph of Bacon himself was "Unheard, forgotten, buried," it should not be overlooked that his teaching bore fruit when 300 years later Digges, from a Baconian manuscript, constructed a telescope.

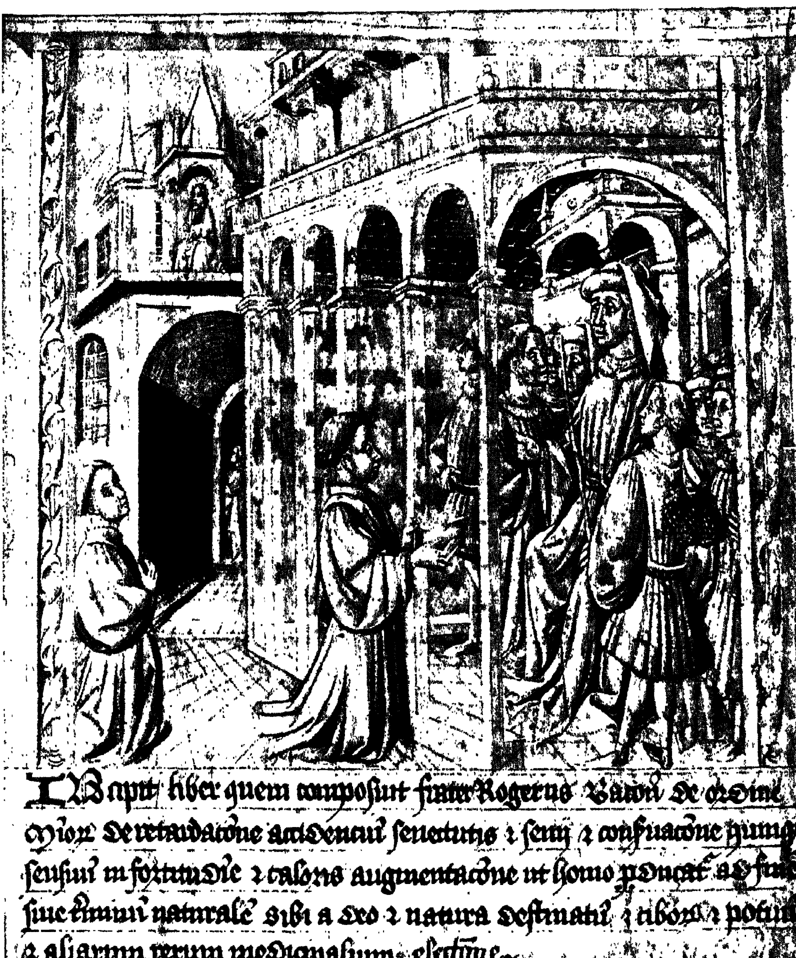
Roger Bacon also wrote letters to the Paris University "Of the Secrets of Arts and Nature," a fact which helps to explain the pleasing scene depicted in Plate I. In this interesting engraving Roger Bacon is shown presenting a book, probably to the Chancellor of Paris. A translation of the inscription is as follows:

> "Here begins the book which brother Roger Bacon of the Minorite Order wrote on the retardation of the concomitants of

ROGER BACON; DOCTOR MIRABILIS,
(1214–1292)

ONE OF THE EARLY FOUNDERS OF SCIENTIFIC THOUGHT IN OXFORD.

"Sine experientia nihil sufficienter sciri potest."



Bodleian MS. 2927.

IT IS BELIEVED THAT THIS SCENE REPRESENTS ROGER BACON, WHO WROTE LETTERS "OF THE SECRETS OF ARTS AND NATURE" TO THE PARIS UNIVERSITY, PRESENTING A BOOK TO THE CHANCELLOR OF THAT UNIVERSITY.

old age and senility, and on the preservation of the five senses in full vigour, and on the augmentation of warmth, whereby a man may reach the natural end or limit destined for him by God and Nature, and on the selection of food and drink and other things with medicinal properties."

I am indebted to Dr. Cowley, of the Bodleian Library, also to Mr. R. T. Gunther, for permission to reproduce this illustration, which forms the frontispiece of Volume II of Mr. Gunther's interesting and valuable book, "Early Science in Oxford." He there uses, with reference to this phase of early knowledge regarding science, the following interesting words:

> "In the twelfth century wandering scholars like Adelard of Bath, brought back the rudiments of physical and mathematical science from Cordova and other southern towns where such studies could flourish. In northern Europe the demonstrative sciences had been neglected, owing, as John of Salisbury would have us believe, to the mistranslation of parts of Aristotle's works that related to physics, for which he rebukes his teachers.
>
> "Not satisfied with the teaching of the most learned professors in Paris, where English scholars took their place as one of the 'nations' of the French university, many a student travelled to Italy and Spain impelled thither by the desire to draw nearer to the fountain-head of knowledge, and on his return found hundreds ready to reverence the 'master,' and to sit at his feet until the advent of one more newly arrived.
>
> "The greatest of these travelled scholars, and one whose acquaintance with Greek and Arabic enabled him to take full advantage of the knowledge to be obtained in foreign countries, was the pupil of Edmund Rich of Abingdon, our 'Doctor Mirabilis' Roger Bacon. His marvellous discoveries and turns of thought, his use and knowledge of instrumental methods, bring him at every turn close to the science of the present day. He is generally recognised as the first great physicist in the modern sense of the word, though we have no means of knowing exactly how much he learnt from those with whom he may have studied when abroad, or how much was due to his astounding and inventive genius. He is unfortunately reticent as regards the construction of his instruments; perhaps he hardly realised that such information would be required a thousand years after his death. For our present purpose it suffices that his improved clock, his lenses and burning glasses, and his telescope entitle him to the most honourable mention in any history of the origin of astronomical instruments; while to him we owe the earliest Astronomical Observatory in Oxford."
>
> "Tradition has it that the earliest astronomical observatory in Oxford was situated on the only spot that is definitely connected with the name of Roger Bacon. Sad to say, the original building was sacrificed in the eighteenth century to an ill-considered scheme for road-widening."

Oxford can indeed be proud of this early Master of Science, whose Opus Majus displayed a mode of philosophising far in

advance of the age in which he lived, and will ever remain as witness of his greatness. This work, alas, only gained him a prison; in his own words he was "forgotten, buried out of sight."

The surpassing merit of the works of Roger Bacon was first publicly recognised in modern times at a meeting of the Royal Society on March 20th, 1678–9, but it is now generally admitted, as also stated by Green, in his "History of the English People," that he should be first in the great roll of those whom, he considered, came under the term Modern Science. He was one of the first to see the enormous importance to mankind of the study of that branch of knowledge which we now call Science, and he would have nothing to do with occult phenomena—a specially interesting and significant fact considering the age in which he lived. Roger Bacon's dictum was "Sine experientia nihil sufficienter sciri potest."

As so well put by Sir William Osler, in the Address already mentioned, the remarkable modernity of Bacon's outlook may be judged from the following sentence:

> "Experimental science has three great prerogatives over all other sciences—it verifies conclusions by direct experiment, it discovers truths which they could never reach, and it investigates the secrets of nature and opens to us a knowledge of the past and of the future."

Alas, the temper of that age was against scientific or philosophical studies, and some centuries had to pass until another Bacon, Lord Verulam, kindled the fire which has grown and grown in importance until to-day we see its wonderful effect upon this world of ours, not merely from the theoretical point of view, but in the innumerable applications of science and its benefits to our daily lives.

The Middle Ages and the Renaissance.—Though there was for a time no one to continue the work commenced so brilliantly by Roger Bacon, it is satisfactory to note that this country held a conspicuous position in the philosophy of the Middle Ages—in fact, Professor de Morgan gives a list of no fewer than 96 English Mathematical and Astronomical writers between 1068 and 1599, so that it was rightly said by Captain Smythe in his *Celestial Cycle* that "England has contributed her full quota to the series of philosophical and zealous inquirers who have so largely opened the human intellect."

Evidently, however, some change disastrous to the fortunes of science must have taken place about 1230, soon after the foundation of the Dominican and Franciscan orders, for the members of these orders fell back upon the adoption of the Aristotelean Philosophy. This unfortunately resulted in deferring for quite three centuries the reforms in study which Roger Bacon had urged as matters of crying necessity in his own time.

Most useful work was being carried out during this period by Continental Universities, high amongst which ranked the University of Paris already mentioned in connection with Roger Bacon. Monsieur Emile Picard, Secretary-in-Chief of the French Académie des Sciences, has pointed out that as regards the Middle Ages, Duhem emphasises in highly referenced works, the brilliancy of the Paris University during the fourteenth and fifteenth centuries, a period of intense intellectual life, where the influence of the teachings of Paris was very considerable on the teaching of the Universities of England, Italy, Spain, and Germany.

After him, Jean Buridan, rector of the University of Paris from 1327, must be reckoned amongst the founders of modern dynamics. Up to then, dynamics had not played any part in the notoriety of Buridan, and, without mentioning the Tour de Nesle, his name only recalls arguments relating to the liberty of indifference, of which, however, no trace is found in his writings. There seems to be no doubt that after Duhem had expounded the dynamics of Buridan by following a manuscript from the Latin part of the National Library, Buridan had broken away from peripatetic mechanics, and it seems that with this theory of the " impetus," he rose to the law of inertia ; whilst daring to proclaim as useless the mental driving force of the celestial orbs, which played such an important part in the physics of Aristotle. Amongst the disciples of Buridan figures in the first rank Nicole Oresme, grandmaster of the College of Navarre in 1356, and later Bishop of Lisieux, whose influence was considerable : Oresme was not only a precursor of Copernic by the views which he propounded on the earth and the planets, but also of Descartes by the use he made of the essential principles of analytical geometry.

After the death of Roger Bacon there was, in this country, practically no advance in true science until the sudden awakening which occurred in the latter part of the sixteenth

century. Then and thereafter progress was rapid and cumulatively so.

During a period represented roughly by the second half of the sixteenth century and the first half of the seventeenth, the status of science was raised enormously by the foundation of an academy in Italy to which reference is made later when dealing with the events which preceded the formation of the Royal Society. It was fortunate that during this period we were able to claim as our countrymen those two great pioneers, Dr. Gilbert (1544–1603) and Sir Francis Bacon (1561–1626).

Dr. Gilbert of Colchester, Physician to Queen Elizabeth, made discoveries in magnetism and electricity which caused him to be known as the Father of Magnetism. He is even credited by some to have been the first to show that metaphysics must give place to science, and Aristotelean ideas cease to dominate thought. To quote Dr. E. F. Northrup:

> "Then Metaphysics gave place to Science, and Aristotle ceased to dominate thought, because there came as it were a gift from Heaven in the form of a desire on the part of men to learn about Nature through controlled observation. Whilst Francis Bacon formulated in a speculative way the new scientific method, it was Gilbert, the Father of Magnetism, who first put into effect, and reported in 1600 his success in his classic *De Magnete*. The Science of Nature as observed in our dwelling place, the earth, made an advance comparable to the butterfly emerging from its chrysalis."

To Sir Francis Bacon, afterwards Lord Verulam, Viscount St. Albans, Lord Chancellor of England, whose portrait is shown in Plate II, we owe that announcement of the new scientific method which did so much to sweep away the earlier systems and admit the light of scientific truth. His various works, and particularly that on the Instauration of Science, have caused him to be regarded as the creator of the school of experimental philosophy. He was in a large measure responsible for the founding of the Royal Society; for it was whilst the memory of Bacon was recent, and the spirit of his philosophy newly spread, that the establishment of this great scientific society was accomplished. After falling from his high political estate, he devoted his remaining years to scientific pursuits. His life, alas, fell a sacrifice to some philosophical experiments. A retort which he had been using burst, some fragments struck his face, and the wounds induced fever, of which he died.

The sixteenth and seventeenth centuries brought a revival

PORTRAIT OF FRANCIS BACON, BARON OF VERULAM, VISCOUNT ST. ALBAN (1561–1625), LORD CHANCELLOR OF ENGLAND, WHO INSPIRED THE ROYAL SOCIETY.

Fr. Verulam Canc

interests, and the commencement of English scientific studies, which are admirably described in Green's *History of the English People*. Speaking of those times the late Professor Green said :

> "It was this lofty conception of the position and destiny of natural science which Bacon was the first to impress upon mankind at large. The age was one in which knowledge was passing to fields of enquiry which had till then been unknown, in which Kepler and Galileo were creating modern astronomy, in which Descartes was revealing the laws of motion, and Harvey the circulation of the blood. But to the mass of men this great change was all but imperceptible; and it was the energy, the profound conviction, the eloquence of Bacon which first called the attention of mankind as a whole to the power and importance of physical research. It was he who by his lofty faith in the results and victories of the new philosophy nerved his followers to a zeal and confidence equal to his own. It was he who above all gave dignity to the slow and patient processes of investigation, of experiment, of comparison, to the sacrificing of hypothesis to fact, to the single aim after truth, which was to be the law of modern science."

In Macaulay's *History of England* there are also striking passages relating to the wonderful developments of the seventeenth century, and it is satisfactory to note that our country is awarded its deserved position of eminence. Macaulay said that:

> "English genius was then effecting in Science a revolution which would, to the end of time, be reckoned amongst the highest achievements of the human intellect. Bacon had sown the good seed in the sluggish soil and in an uncongenial season.
>
> "In the year 1660 the new field of Science obtained ascendancy. In that year the Royal Society, destined to be a chief agent in the long series of glorious and salutary reforms, began to exist. In a few months experimental science became all the mode. The transfusion of blood, the ponderation of air, the fixation of mercury, succeeded to that place in the public mind which had been lately occupied by the controversies of the Rota. Dreams of perfect forms of government made way for dreams of wings with which men were to fly from the Tower to the Abbey, and of double-keeled ships which were never to founder in the fiercest storms. All classes were hurried along by the prevailing sentiment. Cavalier and Roundhead, Churchman and Puritan, were for once allied. Divines, Jurists, Statesmen, Nobles, Princes swelled in triumph of the Baconian philosophy.
>
> "Poets sang with emulous fervour the approach of the Golden Age. Dryden, with more soul than knowledge, joined his views to the general acclamation, and foretold things which neither he nor anybody else understood. In his great poem *Annus Mirabilis* he predicted that the Royal Society would soon lead us to the extreme verge of the globe, and there delight us with a better view of the

Not long afterwards, in the next century, followed the remarkable invention and development of steam power by James Watt, whence largely sprang the industrial development of the nineteenth and twentieth centuries. Before proceeding, however, to outline the "rise of steam" and its consequences, it is necessary to pay tribute to the work of some of the early metallurgists and chemists who laid the foundations on which later workers have built.

Dud Dudley (1599-1684).—One of the earliest practical workers in the manufacture of iron upon a commercial scale was Dud Dudley, to whom the world owes the method of smelting iron by means of coke derived from "pit coale" instead of by charcoal as formerly used. But for his invention the manufacture of cast-iron on its present immense scale would have been impossible. His process of smelting iron may be said to have laid the foundation stone of our vast iron and steel industry.

Dud Dudley, who was the fourth son of Edward Lord Dudley, was born in 1599 about eight miles outside Birmingham. He was educated at Balliol and, according to his own account, was eventually brought down from Oxford to supervise a furnace and two forges belonging to his father at Pensnet, Worcestershire. It was here that Dudley claimed to have made a small quantity of iron of good quality with pit coal, and in the next year many tons which were "fined" at the Cradley Forges. His words run as follows:

> "Having former knowledge and delight in Iron Works of my Fathers, when I was but a Youth: afterwards at 20 years Old, was I fetched from *Oxford*, then of *Bayliol* Colledge, *Anno* 1619, to look and manage 3 Iron Works of my Fathers, 1 Furnace, and 2 Forges in the Chase of *Pesnet*, in *Worcestershire*, but Wood and Charcole, growing then scant, and Pit-coles, in great quantities abounding near the Furnace, did induce me to alter my Furnace, and to attempt by my new Invention, the making of Iron with Pit-cole, assuring myself in my Invention, the loss to me could not be greater then others, nor so great, although my success should prove fruitless: But I found such success at first tryal animated me, for at my tryal or blast, I made Iron to profit with Pit-cole, and found *Facere est Addere Inventioni*."

The immediate practical success of his work may be judged from his statement that he made

> "anually great store of Iron, good and merchantable, and sold it unto diverse men . . . at Twelve pounds per Tun."

It appears, however, that he was litigious and was often in trouble, bringing legal actions against many of those with whom he worked. He took a prominent part in the Civil War as a Royalist and was a Colonel in the army of Charles I, and General of Ordnance to Prince Maurice. In 1642 he was engaged in making cast-iron cannon at his foundries for the Royalist troops. On account of these activities he was subsequently deprived of his estate. In 1660 he begged for the restoration of his privileges, but without success.

In his recent interesting work, "Iron and Steel in the Industrial Revolution," Mr. T. S. Ashton, M.A., Senior Lecturer in Economics in the University of Manchester, deals with the history of Dud Dudley, and refers to the fact that in 1621 Lord Dudley was granted a Patent which apparently ran for thirty-one years in respect of the process followed by his son, Dud Dudley.

In 1665 Dud Dudley published that remarkable book entitled, "Metallum Martis: or, Iron made with Pit-coale, Sea-coale, etc., and with the same Fuell to Melt and Fine Imperfect Mettals, and Refine Perfect Mettals." He spoke of this country being able to supply "His Sacred Majestie's other Territories with Iron and Iron Wares and Steel also, by Iron and Steel made with Pit-coale, Sea-coale, and Peat; and thereby be helpful unto themselves and England and all Plantations of His Majestie's, on this side and beyond the line." In this book which was apparently written in support of his petition for the restoration of his estate, he claimed that iron produced by his method was superior to that smelted and fined with charcoal. Mr. Ashton, in the treatise already mentioned, is inclined to consider that some of these claims were exaggerated; still, on the whole, Dud Dudley was surely entitled to great credit for his work and investigations in those early days of the metallurgy of iron.

It was also Dud Dudley who obtained a quaint acknowledgment of his service to Captain John Copley regarding the manufacture of iron. It runs as follows under date December 30th, 1656:

> "Memorandum—The day and the year above written, I, John Copley, of London, Gentleman, Do acknowledge that after the Expense of diverse Hundred Pounds to Engineers, for the making of my Bellows to blow, for the making of Iron with Pit-Coale or Sea-coale near Bristow, and near the Forrest of Kings-wood; that Dud Dudley Esq. did perform the blowing of the said Bellows at

the Works or Pit above said; a very feisible and plausible way, that one man may blow them with pleasure the space of an hour or two; and this I do acknowledge to be performed with a very small charge, and without any money paid to him for the same invention."

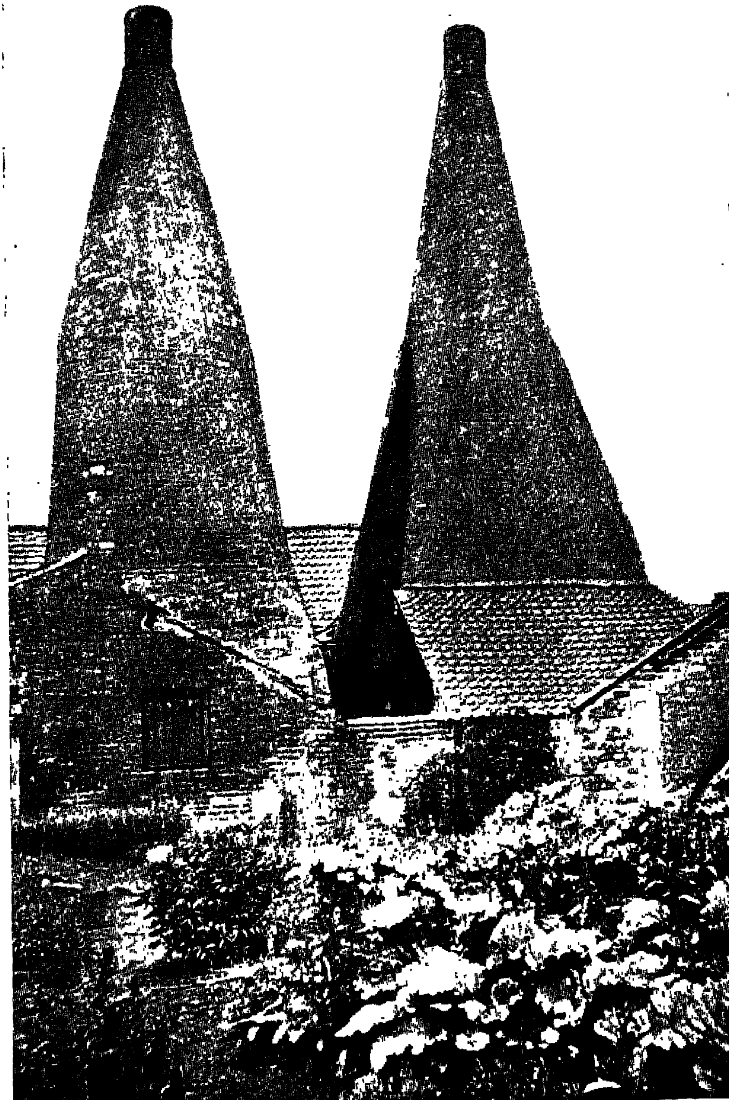
Other Early Metallurgists. In a paper read before the London Association of Foremen Engineers in December 1924, Mr. Pearman refers to the importance of Dud Dudley's work and mentions also the work of Ralph Hogge, 1543, and the Fuller family, who took for their device "Carbone et forcipibus," which properly meant "With Charcoal and Tongs." There was an important output of iron manufactured in Sussex, which reached its zenith towards the close of the reign of Elizabeth. In those times trade became very prosperous and large quantities were exported in the form of ordnance.

In 1665, the same year that Dud Dudley published his *Metallum Martis*, Andrew Yarranton (1616–1684) appears to have been commissioned to go to Saxony with a view to learning the methods of tin-plate manufacture. Yarranton, who is described as an engineer and agriculturist, "entered iron manufacture" in 1652, and after his visit to the Continent he and his friends laid the foundations of the great tin-plate industry of to-day.

The famous ironworks of Coalbrookdale were founded by Abraham Darby in 1709 and, though he died shortly afterwards, his descendants carried on the work with great success. It is recorded of the second Abraham Darby that he watched the charging of the first furnace for six days and nights and was on the point of collapsing from fatigue when the outflow of molten metal proclaimed the success of the experiment.

Richard Reynolds (1735–1816), a Quaker ironmaster of Bristol, went into partnership with a later Abraham Darby whose daughter he married. He finally took sole charge of the Coalbrookdale ironworks, then the most important in England, and amongst his many services to metallurgy and engineering may be mentioned his experiments with the iron puddling process, his use of iron instead of wood for rails, and the fact that he made cylinders for most of the early steam engines.

In 1740, Benjamin Huntsman, originally a Doncaster clockmaker, started experimental work with a view to producing better steel for springs. As a result of his investigations he



CEMENTATION FURNACES BUILT BY BENJAMIN HUNTSMAN about 1750.

developed the manufacture of crucible steel and the works which he established for this purpose at Attercliffe (Sheffield) are still in operation. Plate III shows the cementation furnaces built by Benjamin Huntsman about 1750.

The ingenious and meritorious improvements introduced by Cort in 1786, and protected by patents, consisted in the production of bar wrought-iron by piling and faggoting and by rolling with grooved rollers as is now the common practice.

Until Bessemer invented his steel-making process in 1855, steel was made only by the crucible process or by cementing puddled iron. The production of cheap steel in the quantities to which we are accustomed to-day would be impossible but for the Bessemer process, in the perfection of which Thomas and Gilchrist took such an important part.

To these and other pioneers, some of whom are mentioned in later chapters, we owe much of the prosperity of our Empire and, indeed, it is not too much to say that civilisation as we know it to-day would be impossible but for their discoveries.

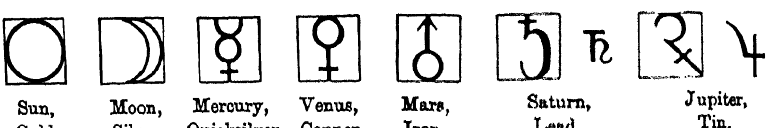
Chemistry in Olden Times.—In his excellent treatise on "The History of Chemistry" covering the period from 2000 B.C. to A.D. 1910, Sir Edward Thorpe, F.R.S., points out that chemistry as an art was practised thousands of years before the Christian era, but as a science it dates no farther back than the middle of the seventeenth century. Although the monumental records of Egypt and the accounts left by Herodotus and other writers show that the ancient Egyptians had a knowledge of processes essentially chemical in their nature, yet there is no certain evidence that the Egyptians ever pursued chemistry in the spirit of science, or even in the manner which they and the Chaldeans followed, for example, astronomy and mathematics.

It is believed that the origin of the word "Chemistry" was from "chemi," meaning the "black land," the ancient name of Egypt. It was known as the "black art," which may have signified "Egyptian art" rather than that of doubtful nature.

Thorpe traces in a most graphic and interesting manner the rise of alchemy; the philosopher's stone; iatro-chemistry; and phlogistonism. We then come to Lavoisier and La Révolution Chimique; the atomic theory of Dalton and others which superseded previous conceptions; and then we have the beginnings of electro-chemistry; the foundations of organic chemistry, and the rise of physical chemistry.

As showing the ignorance and mystery prevailing so comparatively recently as two hundred years ago, it may be recalled that even such a pioneer as Dud Dudley says, with reference to iron manufacture: "I might here speak somewhat of Superior Planets producing Metal; Saturn, Lead; Jupiter, Tin; and Mars, Iron." This was evidently before the days of spectrum analysis!

Chemists in the days of alchemy were not content with merely stating the names of metals, but these were also represented by curious symbols or zodiac signs as shown by the following figure, which is taken from Glauber's "Treatise of the Signature of Salts, Metals, and Plants," published in 1658. In this the Sun represents Gold; the Moon, Silver; Mercury, Quicksilver; Venus, Copper; Mars, Iron.



In explanation of these symbols, Glauber said:

> "The extent to which the symbol touches the enclosing squares is intended to indicate the relative perfection of the metal. Now if into one of these I put the character of the Sun or Gold, viz. a round circle, it touches four parts of the square and filleth it up, signifying that among celestial and terrestrial creatures, the Sun and Gold do excel all other things in their perfection."

Saturn was supposed to influence life, sciences and buildings; Jupiter—honour, wishes, and wealth; Mars—wars, persons, marriages, and quarrels; the Sun—hope, gain, and happiness; Venus—love and friendship; Mercury—fear, disease, debts, and commerce; the Moon—robberies, wounds, and dreams. The intrinsic quality was denoted by the planet. The Sun was regarded as favourable; Saturn, cold; Jupiter, temperate; Mars, ardent; Venus, fruitful; Mercury, inconstant; the Moon, melancholy. The days, colours, and metals also came under the same influences.

Famous Chemists.—It would be too ambitious a task to enumerate the names of all those who have contributed to the present advanced state of chemical knowledge, but the names

and dates of some of the most notable chemists, from the Middle Ages down to the present time, are given in Table I. The " type " classification adopted in this Table is based on the method introduced by Sir William Tilden, F.R.S., in his valuable book " Famous Chemists : the Men and their Work."

TABLE I

NOTABLE CHEMISTS FROM THE FIFTEENTH CENTURY TO THE PRESENT DAY.

The " type " classification here used is based on the method suggested by Sir William Tilden, F.R.S.

IATRO-CHEMISTRY	
Paracelsus	1494–1555
Agricola	1490–1555
Glauber	1604–1668
Van Helmont	1577–1644
THE BEGINNINGS OF MODERN CHEMISTRY	
*Robert Boyle	1627–1691
Mayow	1615–1679
Boerhaave	1668–1738
Hales	1677–1761
THE PHLOGISTIANS	
Stahl	1660–1734
Black	1728–1799
Cavendish	1731–1810
Priestley	1733–1804
Scheele	1742–1786
Bergman	1735–1784
Cronstedt	1722–1765
Réaumur	1683–1757
THE ANTIPHLOGISTIC REVOLUTION	
Lavoisier	1743–1794
Berthollet	1748–1822
Vauquelin	1763–1822
Klaproth	1743–1817
Berthier	1782–1843
ELECTRICITY IN THE SERVICE OF CHEMISTRY	
Franklin	1706–1790
Davy	1778–1829
Wollaston	1766–1826
Faraday	1791–1867
Henry	1797–1878
Hare	1781–1858
Silliman	1772–1860
LAWS OF COMBINATION AND THE ATOMIC THEORY	
Proust	1755–1826
Dalton	1766–1844
Gay-Lussac	1778–1850
Berzelius	1779–1848
Thénard	1777–1857

* The Father of Modern Chemistry and the original user of the word " Analysis."

Molecule and Atom Defined

Avogadro	1776–1856
Cannizzaro	1826–1910
Prout	1786–1850

Early Attempts at Classification

Dumas	1800–1884
Liebig	1803–1873
Hofmann	1818–1892
Bunsen	1811–1899
Playfair	1819–1898
Roscoe	1833–1915
Kirchhoff	1824–1887
Wöhler	1800–1882

Theories of Chemical Action and Constitution of Molecules

Williamson	1824–1904
Frankland	1826–1899

Classification and Nature of Elements

Crookes	1832–1919
Mendeléeff	1834–1907
Ramsay	1852–1916
Travers	
Moseley	
Aston	

Physical Chemistry

Rumford	1753–1814
Dulong	1785–1838
Mitscherlich	1784–1863
Graham	1805–1869
Tyndall	1820–1893
Maxwell	1831–1879
Abel	1827–1902

Arrhenius
Bancroft
Clarke
Cooke
Crossley
Donnan
Gibbs
Haber
Harker
Hatschek
Kelvin
Langley
Langmuir
Lockyer

Van't Hoff
Morley
Nernst
Onnes
Ostwald
Porter
Rayleigh
Remsen
Richards
Sabatier
Thomson, J. J.
Thorpe, J. E.
Threlfall
Walker
Wenzel

Stereo-Chemistry

Dobbie	
Le Bel	
Van't Hoff	1853–1911

Chemistry of the Radio Active Elements

Bragg, W. H.
, W. L.

Becquerel
Rutherford
Soddy

ORGANIC CHEMISTRY

Baeyer	Gerhardt	Pelouze
Berthelot	Haller	Perkin
Cahours	Kekulé	Richter
Chevreul	Ladenburg	Robertson
Debus	Laurent	Thorpe, J. F
Fischer, E.	Moureu	Wurtz
Frémy	Pasteur	

MODERN CHEMISTRY Is it all (entirely) English?

Armstrong	Frankland, P.	Pope
Baker	Jackson	Scott
Beilby	Lowry	Tilden
Dewar	Meldola	Wynne
Dixon	Morgan	Young
Forster	Perkin, W. H., Jun.	

Robert Boyle (1627-1691).—Generally and deservedly known as the "Father of Modern Chemistry," Robert Boyle was born in Ireland, and lived during the period 1627-1691. His portrait, reproduced in Plate IV, is from an engraving "done after the marble bust in her Majesty's Hermitage in the Royal Garden at Richmond." He was sent to Eton, the Provost of which then was Sir Henry Wotton, who was described by Boyle as "not only a fine gentleman himself, but well skilled in the art of making others so." He was of such delicate constitution that it is stated "he had divers sorts of cloaks to put on when he went abroad, according to the temperature of the air, and in this he governed himself by his thermometer." No stranger of note visited England without seeking an interview with him; three successive Kings of England conversed familiarly with him, and he was considered to have inherited, nay, even outshone, the fame of the great Verulam.

His services to science were unique, and he had all the advantages of being in touch with the great men of the day, including Newton, Locke, Evelyn, and others.

He was a natural philosopher and chemist, and it is stated it was he who first used the word "analysis."

Whilst no great discovery is attached to his name, his life-work "implied an advance all along the line." He was the first to prepare hydrogen, the first to distinguish between chemical compounds and mixtures, and the first to introduce into Oxford the regular teaching of practical chemistry. With him originated the definition of an element as a hitherto undecomposed constituent of a compound. In the year 1665 he received the degree of Doctor of Physik.

As showing the love he had for his work, in 1649 he wrote to his sister, Lady Ranelagh, saying "Vulcan has so transported and bewitched me as to make me fancy my Laboratory a kind of Elysium." Probably sometimes we do not all feel that way!

He was known as the "Christian Philosopher," and was much interested in missionary work, giving large subsidies out of his fortune, including gifts for the preparation of the first Bible printed on the American Continent in the language of the Cherokee Indians.

Priestley (1733-1804).—Dr. Joseph Priestley, whose portrait is shown in Plate V, was an extraordinary combination of Theologian, Philosopher, and Chemist. Born in 1733 at Fieldhead, Birstal, near Leeds, he lived at Warrington from 1761 to 1768; at Leeds from 1769 to 1773; and at Birmingham from 1780 to 1791; and then went to the United States in 1794, where he died in 1804.

Priestley had a meeting with Dr. Benjamin Franklin, during one of his visits to London, which caused him to take up the study of electricity, and eventually to write a history of the knowledge then existing on that subject. This, together with several new electrical experiments, won him considerable reputation and resulted in his election as Fellow of the Royal Society in 1766. It is interesting to note that Benjamin Franklin was one of Priestley's proposers when his name was submitted to the Royal Society for election.

Though he is best known, and rightly so, by reason of his chemical discoveries, it is somewhat curious that Priestley did not abandon the subject of electricity in favour of chemistry until comparatively late in life.

By his great discovery of oxygen, Priestley made for himself an undying name. Whilst this contained the germ of the modern science of chemistry, yet, owing to his blind faith in the phlogistonic theory, the significance of his work was to some extent lost upon him. The first announcement was made by him in a letter dated March 15th, 1775, which was read at the Royal Society on May 25th of that year.

Priestley's account of the discovery of oxygen is given in his own words as follows:

> "Having procured a burning lens, I proceeded with great alacrity to examine by the help of it, what kind of air a great variety of substances would yield, putting them into vessels filled with quicksilver, and kept inverted in a basin of the same. After a variety of

ROBERT BOYLE, F.R.S.
(1627–1691)
THE FATHER OF MODERN CHEMISTRY.

JOSEPH PRIESTLEY, F.R.S.
1733–1804.

MATTHEW BOULTON, F.R.S.
1728–1809.

other experiments, I endeavoured to extract air from mercurius calcinatus *per se ;* and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss how to account for it."

His experiments showed him that this air "had all the properties of common air, only in much greater perfection," and he called it "Dephlogisticated air," regarding it simply as very pure ordinary air.

It was in Paris, however, in October, 1774, where Priestley, according to his account, spoke with the great French chemist, Lavoisier, of the experiments he had already performed, and those he meant to perform, in relation to the new gas. Fifteen years later Priestley declared specifically that he had told Lavoisier of his experiments during this visit to Paris. This fact is mentioned because at one time it was thought that Lavoisier might have been the first to make the great discovery, but this was not so.

Apart from his work in connection with the discovery of oxygen, Priestley also discovered carbon monoxide. His invention of the pneumatic trough was of much service, enabling him not only to discover new gases, but to investigate more fully the properties of many already partially known.

There were serious riots in Birmingham in 1791, probably meant to commemorate the French Revolution in 1789. These partly took the form of an attack, amongst many others, upon Priestley's house at Fair Hill. Fortunately the Doctor was able to get away in safety, but his house was completely gutted.

A local account of the destruction is set forth in the following words :

"They destroyed an apparatus of philosophical instruments, and a collection of scientific preparations for ascertaining the powers and extending the knowledge of Nature, of such number and value as perhaps no individual except Dr. Priestley could have been deprived in any day or country."

An interesting letter addressed to the Town of Birmingham was written by Dr. Priestley regarding this mob attack on July 19th, 1791, in the following terms :

"July 19, 1791.

"To the Inhabitants of the Town of Birmingham.

"My late Townsmen and Neighbours,

"You have destroyed the most truly valuable and useful apparatus of philosophical instruments that perhaps any individual, in this or any other country, was ever possessed of, in my use of which I annually spent large sums with no pecuniary view whatever, but only in the advancement of Science, for the benefit of my country and mankind. You have destroyed the Library corresponding to that apparatus, which no money can re-purchase, except in course of time. But what I feel far more, you have destroyed manuscripts, which have been the result of the laborious study of many years, and which I shall never be able to recompose; and this has been done to one who never did, or imagined, you any harm.

"In this business we are the sheep and you the wolves. We will preserve our character and hope you will change yours. At all events we return you blessings for curses, and hope that you shall soon return to that industry and those sober manners for which the inhabitants of Birmingham were formerly distinguished.

"Yours faithfully,

"J. PRIESTLEY."

An old proverb says: "The ship that carries most sail is most buffeted by the winds and storms." It was so with Priestley; his mental capacity was great, but most severely was he buffeted, specially in the later portion of his career. Nevertheless, he manfully overcame all obstacles and the world is greatly indebted to him for the most valuable developments he helped to bring about, including his important discovery of oxygen, an element now being used on a large scale for many purposes.

Much more might be said, did space permit, concerning other early workers in science, and, in later chapters, reference is made, where possible, to those particularly associated with early metallurgy. In the meantime, it is hoped that some profit and pleasure may be derived from the information given above concerning a few of the more notable men who lit and fanned the flame of scientific inquiry.

CHAPTER II

THE RISE OF STEAM.

The Beginning of the Mechanical Age.—As explained in the preceding chapter the work of Roger Bacon was far ahead of the opportunities, if not the inclinations, of his age, and, indeed, for centuries after his lifetime the progress of science in this country was slow. The real awakening of interest in scientific matters occurred during the seventeenth century, and was both marked and fostered by the foundation of the Royal Society which is also referred to in Chapter XIV. Soon afterwards came the steam engine and, with it, the dawn of the Mechanical Age and the Industrial Revolution.

In an excellent address upon the History of Mechanical Engineering delivered to the Women's Engineering Conference a few years ago, Professor F. W. Burstall, M.A., Dean of the Faculty of Science in the University of Birmingham, said he considered that the first development of engineering came at the end of the Great Rebellion somewhere about 1660, and that the mental outlook then began to change largely from the immaterial and philosophical into the application of science for the purposes of man. The brilliant intelligence gathered round Charles II developed in the direction of the improvement of what may be termed mechanical forces.

In 1705 came the production of mechanical power in the Newcomen engine, brought into use in this country largely because of cheap coal being accessible, and also because of the means it provided of improving the condition of the mines; owing to increased depth these required draining by pumping, which was not possible except by the utilisation of mechanical energy. Old prints exist showing that in 1720 tilt hammers and rolling mills were driven by wooden shafts actuated by water power.

With the exception of these applications, and the use of water wheels for grinding, there were few attempts to utilise

mechanical power prior to 1770, and Professor Burstall is doubtless correct when he says that the great distinction between the old world and the new commenced about this date. This is a striking point to have elucidated, and it has not previously been put so clearly and so well.

Professor Burstall adds that whilst the genius of Watt first laid down the foundation for these wonderful advances, the great work of Boulton, Murdoch, and Wilkinson, must also be remembered. Murdoch first brought out the slide valve for the James Watt engine, and Wilkinson devised the machine tools at the Soho Foundry where the first pumping engines were constructed as early as 1760. It should also be added that it was due to James Watt, Junior, that mechanical power for the propulsion of steamships was introduced in 1807.

A brief survey of the work of those who discovered or invented the basic principles and equipment of the steam engine presents many points of interest and enables us to appreciate, if inadequately, the genius of those pioneers.

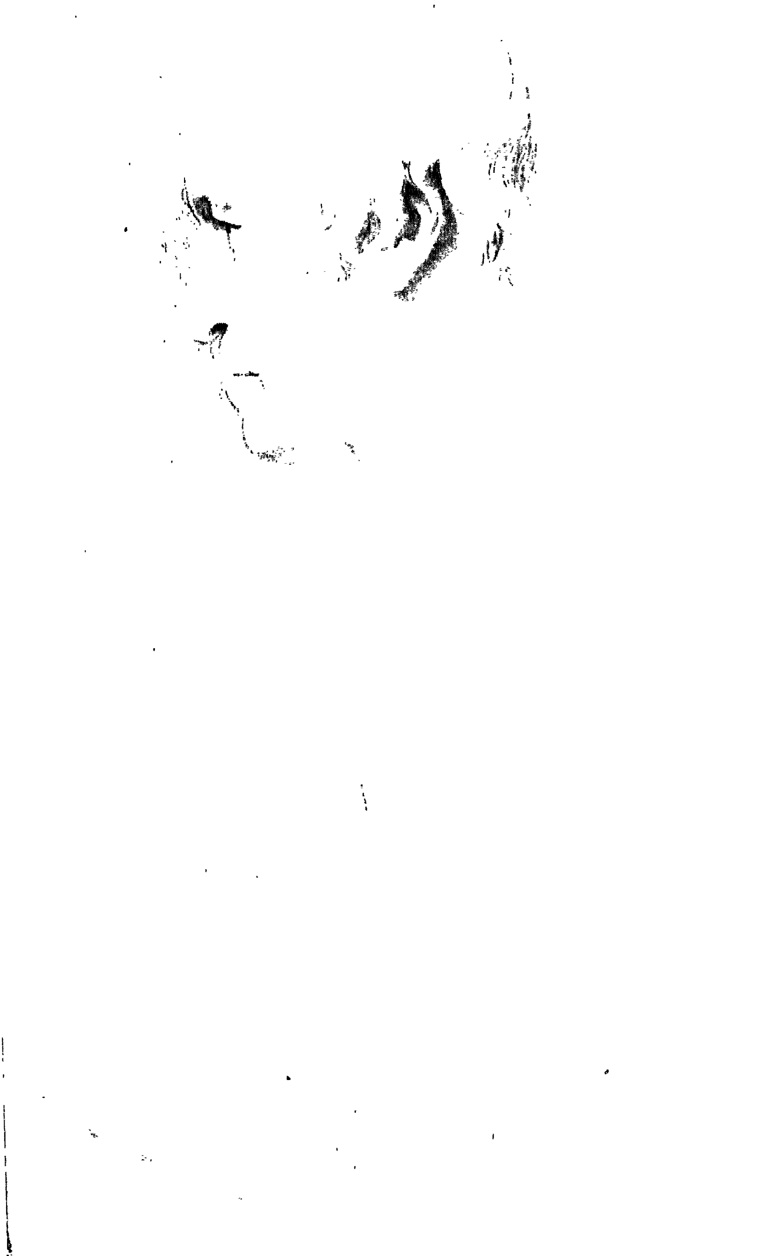
So far back as about A.D. 50, Hero of Alexandria is credited with the earliest known employment of steam as a motive agent, but the next step of any importance does not appear to have been taken until 1700 years later, when Dionysius Papin, of French origin, studied the subject of steam power.

Papin (1647-1714).—It is in no spirit of depreciation of Watt's great discovery and invention, which are referred to later, that attention is called to the work of Professor Dionysius Papin, M.D., Fellow, and, at one time, Secretary of the Royal Society, whose portrait is shown in Plate VI.

In 1681 he published a paper on "A New Digester for Engines," and later, in 1690, a paper in the *Acta Eruditorium Lipsiæ* entitled "A New Method of obtaining very great Moving Powers at Small Cost." On these papers are based Papin's claims to be considered one of the early originators of the steam engine. Papin availed himself of the apparatus of Otto Gueriche and worked out the important fact that if a closed cylinder were filled with steam and the steam then allowed to condense, a vacuum would be formed within the cylinder, and that consequently a movable piston fitted to the interior of the cylinder would then fall under the pressure of the atmosphere.

About the middle of the 17th century the important discovery had been made that the atmosphere was a fluid possessed of weight, the pressure due to which could be excluded at will

DIONYSIUS PAPIN, F.R.S.
(1647–1714).



JAMES WATT.
(1736-1819).

from the interior of a closed vessel so as to obtain a vacuum; this was the foundation of the development of the steam engine.

In Papin's experiment there was some suggestion of the principle of Newcomen's engine, but the proposal was abandoned by him.

Previous to this, he had made an unsuccessful attempt to obtain a vacuum by the explosion of gun-powder in the small cylinder beneath the piston, a description being published in September, 1688, in the *Acta Eruditorium Lipsiœ.*

It is possible that Papin may have had his attention drawn to the subject by reading a book published in London in 1651 by an unknown Author, entitled *Invention of Engines of Motion lately brought to perfection whereby may be despatched any work now done in England or elsewhere (specially works that require strength and swiftness), either by wind, water, cattel, or men, and that with better accommodation and more profit than by anything hitherto known or used.*

Although Papin overlooked the difficulties of applying power to various mechanical processes, he was best known in England on account of his Digester, described by him in the paper previously mentioned. His works are rare and it is doubtful whether more than a single copy of the Memoir of 1690 is in existence. The fact that Papin was at one time Secretary of the Royal Society shows that he must have been a man of considerable knowledge.

Papin described in 1707 an inferior sort of steam engine, in the preface to a little work entitled *Nouvelle manière d'élever l'eau par la force du feu,* printed at Cassel.

Besides showing the power of steam by the famous experiment of his Digester, he proposed in a pamphlet printed in 1695, the construction of a new pump, the pistons of which were to be moved by the steam of boiling water.

Whilst Papin's early work is fully admitted, as a well-known French writer at the time said: "It is a great thing even to suggest this idea, but it remained to realise and execute it in a simple and convenient manner. The English, referring chiefly to Watt, are the first who have succeeded in that."

Savery (1650-1715) and Newcomen (1663-1713.)—In 1698 Thomas Savery patented and constructed what was known as the "fire engine." It is possible that he was indebted to the Marquis of Worcester. In any case, however, it may be safely

said that he was the first to utilise fuel as a practical means of performing mechanical work.

Then came Newcomen assisted by John Cawley, both of Dartmouth, who following in Papin's steps, succeeded prior to 1712 in perfecting the atmospheric engine, from which the growth of the modern steam engine can be clearly traced.

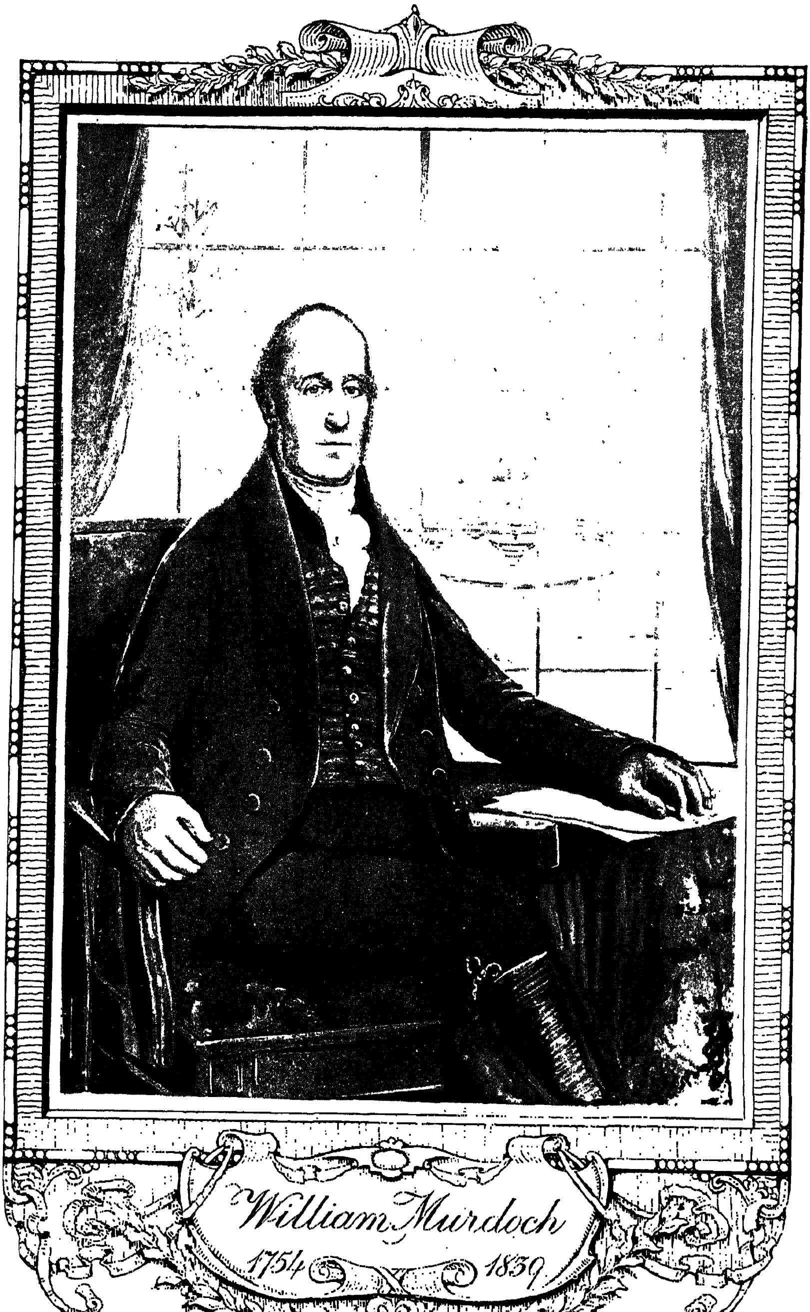
Later on Newcomen and Savery seem to have come to an understanding with each other regarding their patents. Their type of engine remained the standard for upwards of sixty years for draining mines—in fact, down to 1789 nearly 100 engines had been built for the northern districts, and about half that number for Cornwall.

Watt (1736-1819).—To James Watt, whose portrait is shown in Plate VII, belongs the credit of having done more than any other one man to bring the steam engine to perfection. The fame of his work in this field is world-wide.

His discovery of the method of condensing steam in a vessel entirely separated from the cylinder occurred in 1765. He took out his first patent in January, 1769, and this was renewed by Act of Parliament in 1775. Later, in 1778, came his engine on the expansion principle, and his double-acting engine in 1781. In these days of rapid progress it may be interesting to state that James Watt once called Richard Trevithick a murderer, for proposing to operate boilers at the "dangerous" pressure of 60 lbs. per square inch! To-day British engineers are carrying out research work with boilers of the Benson type for operating pressures of about 3,200 lbs. per square inch.

In view of the recent Centenary celebrations of Watt and his work it is not necessary to add anything further here. The Institution of Civil Engineers have honoured his memory by founding the Prize of the Watt Gold Medal, which is awarded annually.

Boulton (1728-1809).—Watt was ably assisted by Matthew Boulton, and later by William Murdoch. Boulton, whose portrait is shown in Plate V, was born in 1728, and started the famous Soho Works in 1762. James Watt joined him in partnership in 1769, and Murdoch came into the firm about 1777. This wonderful triple combination gave us the steam engine, gas lighting, and other industrial developments. William Brunton, the inventor of the first mechanical stoker, was also one of the Soho group of Engineers. His work in this field and, indeed, the whole early history of mechanical stokers, is discussed



William Murdoch
1754 1839

in "Mechanical Stoking" (Pitman) by Mr. David Brownlie, who has devoted much time to the study of the subject.

It is interesting to know that James Watt and Matthew Boulton preserved all the documents relating to their invention and business records. Between 1775 and 1780 all letters directed to customers were copied by the hand of James Watt, but after 1780 the transfer was made by a copying press which he had devised to save himself the tiring process of transcription. All the records, extending from 1775 to 1850, are preserved in the Municipal Reference Library and Assay Office of the City of Birmingham.

Mr. John Lord, in preparing his book "Capital and Steam Power, 1750–1800," went through these historic records, and found that during the first ten years of the invention, sixty-six reciprocating engines were supplied, twenty-two of them being for copper mines and seventeen for ironworks. After 1781 Watt took out his patent for converting the to-and-fro action of the piston into rotary movement by means of the sun-and-planet gear. Of the 144 engines, mainly of this rotative type, erected during the period 1785–1795, it appears that forty-seven were for cotton spinning and twenty-two for collieries. By 1824 the total number of engines proceeding from the Soho works had reached 1164. Thus we see the beginnings of modern steam power development.

Murdoch (1754-1839).—William Murdoch, whose portrait is shown in Plate VIII, was born in 1754 at Lugar, Ayrshire. He was the son of a small farmer, and, as rumour insists, supposed to be of Flemish extraction. After leaving his native village in 1777, he obtained a situation as mechanic with Boulton and Watt. In 1792 he lighted his house and office at Redruth, Cornwall, with gas, and in the same year erected his first gasometer at Birmingham, which gave continuous service from this time until 1911, that is for nearly 120 years. This still stands, though in partial ruin, at the works of Messrs. Avery, Soho Foundry, near Birmingham. Until comparatively recently the gas-holder was intact and was used for the storage of Dowson gas.

In 1798 Murdoch left Cornwall to take up a prominent position at the Soho Works, where he constructed gas-making apparatus on a larger scale ; this included lighting their principal building, and various new methods were practised for washing and purifying gas.

Murdoch designed the gasometer whilst some of the Gas Companies in London were struggling with the use of gas balloons to store the gas. This was the forerunner of the modern gas-holders, some of which have reached huge proportions, as in the case of that of the Gas Light and Coke Co. in London, which has a diameter of 300 feet and a capacity of 12,000,000 cubic feet.

In 1808 he read a Paper before the Royal Society of Arts with regard to his installation of gas-lighting at the Phillips and Lees Cotton Mill in Manchester, containing some 900 gas burners. For this he was awarded by the Society, the Rumford Gold Medal.

Developments in the Nineteenth Century. The long early period of research work in science may now appear to us as of little importance in its intrinsic results, also as having been slow and painful in its progress. But this was not so; the evolution was merely proceeding. The movement culminated in the first half of the nineteenth century, when scientific engineering and metallurgy began to appear. Speaking of the lines of work with which this book is primarily concerned, useful pamphlets and books relating to the engineering and metallurgical arts began to be published during the early part of the nineteenth century. Until, however, Faraday carried out his wonderful researches on electricity little was known of this branch of science. It was he who first opened up this avenue which has led to the practical application of the new form of energy, electricity, which, one might justly say, is being developed and controlled by man to the great benefit of the world generally.

As a small example of this great advance in thought in the early part of the nineteenth century, there is shown in Plate IX an interesting illustration entitled "The Temple of Science," which appeared in *The Engineers' and Mechanics' Encyclopædia* published in 1835. This illustration claimed to comprehend "Practical Illustrations of the Machinery and Process employed in every description of manufacture of the British Empire." The author of the book was Luke Herbert, Civil Engineer, Editor of the *History and Progress of the Steam Engine*, *Register of Arts*, and *Journal of Patents and Inventions*.

The author is indebted to his friend Mr. H. W. Dickinson, Secretary of the Advisory Council of the Science Museum, South

THE TEMPLE OF SCIENCE.

IN THIS ALLEGORICAL ILLUSTRATION, PUBLISHED IN 1835, ARE SHOWN THE VIEWS PREVAILING EARLY IN THE NINETEENTH CENTURY WITH REGARD TO SCIENCE.

Kensington, for the loan of the book from which this illustration has been taken.

In this plate is shown in the distance the first locomotive drawing railway carriages filled with coal or with the gentry of the day wearing "top hats," it is not certain which of them! In the air is an airship or dirigible balloon; in the background a demonstration of the Torricellian vacuum; and an apparatus for the demonstration of static electricity. In the foreground can be seen allegorical figures examining plans of mechanical inventions, including a water-tube boiler and an engine with governor. The foreground is strewn with various tools and apparatus relating to engineering, metallurgy, and chemistry.

It may be recalled that the first locomotive made by George Stephenson in 1814 travelled at the rate of about six miles per hour, whilst the "Rocket," in 1829, possessed what was then considered to be the high speed of 25 to 35 miles per hour.

In the Science Museum at South Kensington, to which further reference is made in Chapter XIII, there may be seen the Boulton and Watt engine, Trevithick's engine, Murdoch's locomotive, Trevithick's locomotive, the "Puffing Billy" locomotive, the "Rocket" locomotive, Parsons' original steam turbine, an historic Panhard motor car, and additional objects of fascinating interest. These and the many other historic exhibits in the Museum deserve to be studied, for, apart from other considerations, they were the stepping-stones by which the marvels of to-day have been reached, and they possess in themselves engineering merits of no mean order. So long ago as 1848 the London to Exeter express regularly maintained a start-to-stop speed of 56·7 miles an hour from London to Didcot. The load hauled was comparatively light—say, 50 to 75 tons—but such speeds were highly creditable at that early stage in the development of railways. How they compare with the railway speeds and loads of the twentieth century will be seen from figures given in the next chapter.

CHAPTER III

THE TWENTIETH CENTURY.

Transport and Communication. In addition to many other important advances in the science of engineering and metallurgy, the nineteenth century saw the birth of railways, steam navigation, electric telegraphs, the telephone, common matches—without which life would be uncommonly inconvenient —gas-lighting, photography, the phonograph, Röntgen rays, spectrum analysis, the use of anæsthetics and antiseptics, the motor car, and wireless telegraphy. Truly a wonderful output for a single century, but one which the twentieth century will, in all probability, exceed. New fields are continually being opened, and in every field progress is cumulative, and more rapid as the resources of science increase.

Already the Wright Brothers' gliders of 1902 have developed into a British aeroplane which crossed the Atlantic in sixteen hours, and it is stated that a British firm, Messrs. Vickers Ltd. is about to build a rigid airship twice the size of the ZR3 which recently made a fine flight from Friedrichshaven to New York in 80 hours.

In May, 1904, the Plymouth to Paddington mail averaged 65½ miles an hour from start to stop, and at times exceeded 100 miles an hour. At present the fastest regular train run in this country is probably that accomplished by the 2.30 p.m. train from Cheltenham to Paddington, which does the 77¼ miles from Swindon to Paddington in 75 minutes (61·8 miles an hour from start to stop) and reaches 83 miles an hour at some parts of the journey. The "Cornish Riviera" runs daily between Paddington and Plymouth, more than 225 miles, without a stop—and this is the longest non-stop run in the world. Such are some of the achievements of our railways.

In Plate LXI there is shown a facsimile of the signature of Robert Stephenson, which is taken from the Charter Book of the Royal Society, of which Stephenson was made a Fellow in

1849. This year (1925) there is to be held in this country the International Railway Congress, when opportunity will be taken, by invitation of the London and North Eastern Railway, to hold a meeting at Darlington after the Congress for special celebration of the date of the opening of the Stockton and Darlington Railway, which took place exactly one hundred years ago.

The huge proportions to which railway transport has risen within the last hundred years can be gathered from the fact that immediately before the war the railway companies in this country were earning about £120,000,000 per annum. The expenditure required to earn this sum was about £80,000,000, corresponding to an " operating ratio " (*i.e.* ratio of expenditure to income) of 66 per cent; the surplus of about £40,000,000 was used partly as remuneration on the capital invested in the undertakings and partly to strengthen the reserve funds. To-day, 1925, the increased rates make the total receipts about £200,000,000 per annum, and the increased costs have advanced expenditure to £160,000,000, so that the operating ratio has risen from 66% to 80%, and the percentage surplus has been reduced accordingly.

The large difference between 1913 and 1925 represents a serious burden, chiefly borne by the industrialists of our country. It is hoped that before long some relief will be afforded. The railroad transport charges are, at present, far too high, and indirectly seriously hamper this country in its competition abroad.

In America, under essentially different conditions, the most striking feature of railway development is perhaps the length and weight of the trains hauled. On the Virginian Railroad a trial trip was recently made of, probably, the longest train which has ever run. A load of 15,400 gross tons in a train of 111 cars, with a total length of 6,100 feet ($1\frac{1}{8}$ miles) was hauled 250 miles by a single locomotive. This tonnage is about as much as that carried by a steamer of 17,000 tons displacement and 460 feet in length.

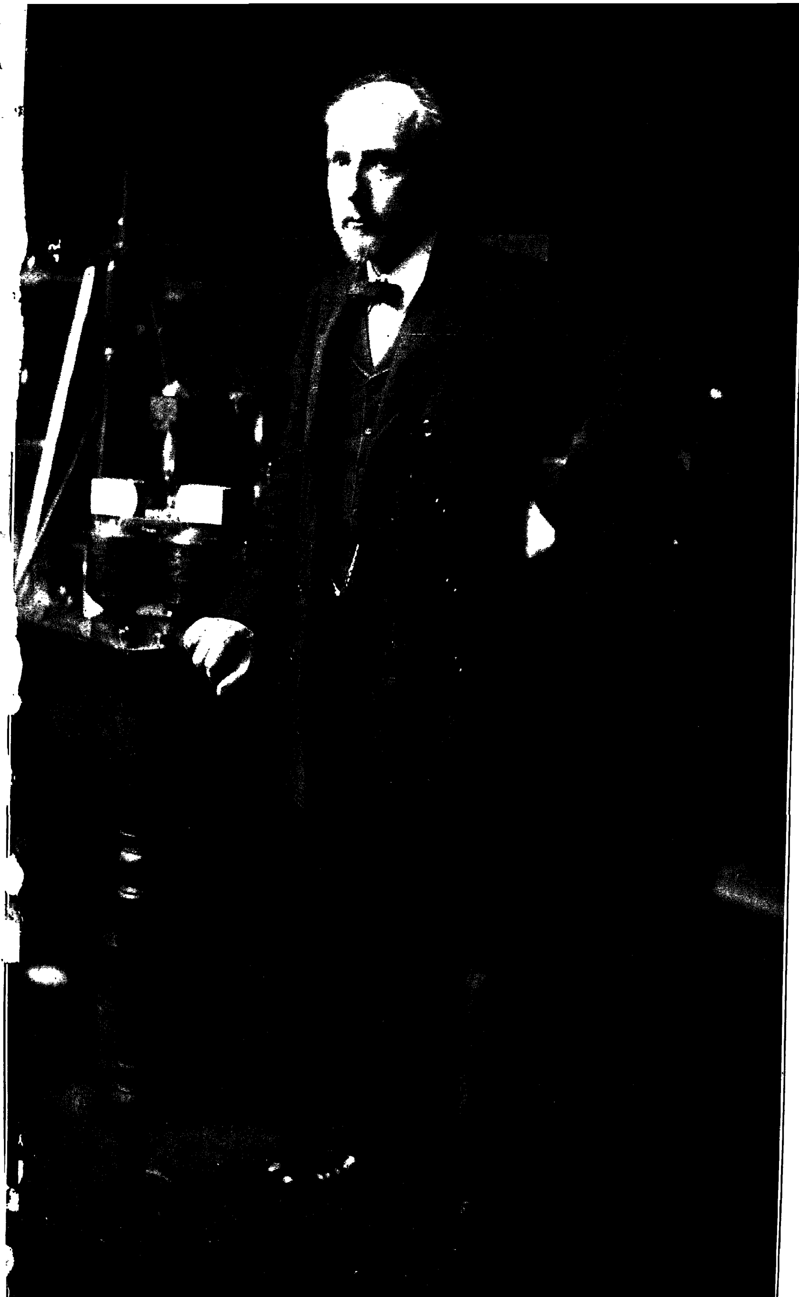
Other achievements of the present day are steamships of some 60,000 tons, over nine hundred feet in length, far excelling the *Great Eastern*, launched only sixty-seven years ago, which was in its day considered a prodigy; motor cars which will carry us comfortably at high rates of speed on our excellent roads—a system of travelling which has further helped to

revolutionise modern life; aeroplanes flying at the rate of ever four miles per minute for those who like such speedy travelling; telephones making possible conversation over a distance of 3,000 miles; wireless with a range so much wider as to be almost incredible; broadcasting, and a thousand and one other developments too numerous to mention, to say nothing of the immense advances brought about in the fields of physics and chemistry where—with our increasing knowledge of atomic structure—there are possibilities too vast to be even guessed.

Low Temperature Research.—One of the most striking developments of the past decade is the increasing extent to which low temperature processes are being employed, not only at or near the freezing-point of water for such purposes as the transport of foodstuffs for thousands of miles in "cold storage," but also within comparatively few degrees of absolute zero—the "nadir of temperature"—for such purposes as the liquefaction of helium. Liquid air, now a common commodity which can be bought at a comparatively low price per pound, is used in oxygen breathing outfits for high-altitude flying and for mine rescue work. Also it forms a powerful but "safe" explosive, and certain rare gases, such as neon, can be isolated as by-products during the liquefaction of the air.

By his work in perfecting liquid air plant the late Sir James Dewar (1842–1923) established for himself a world-wide reputation, and the silvered "vacuum flasks" which he devised specially for the storage of liquid air are now made in millions and used in almost every household to hold hot or iced liquids according to the season.

A portrait of Sir James Dewar in his laboratory is shown on Plate X. The author will always remember with gratitude the great kindness shown to him by Sir James on many occasions. The research which led to the joint paper before the Royal Society in 1904, "On the Effect of Liquid Air Temperatures on the Mechanical and Other Properties of Iron and Its Alloys," was continued by the author who presented to the Iron and Steel Institute in 1905 a paper entitled "Experiments relating to the Effect on Mechanical and Other Properties of Iron and Its Alloys, produced by Liquid Air Temperatures." Sir James was kind enough to place most freely and fully at the disposal of the author and his assistants the various apparatus at the Royal Institution, which were necessary for the continuation and completion of this further research.



THE LATE SIR JAMES DEWAR, F.R.S., IN HIS LABORATORY.

To face page 30

Magnifications." In this paper it is shown that it is now quite possible to prepare and examine metallurgical micro-sections of 8,000 magnification. This means that the diameter of the actual field shown in a $3\frac{1}{4}$-in. circle photograph at this magnification is only 0·00041 in. or 1/2460 in. The area of this field examined is 0·00000013 square inches. The polished section under micro-examination is about $\frac{1}{4}$-in. square. If the whole of this latter area were magnified 8,000 times, it would yield a square about 55 yards by 55 yards, occupying an area of approximately 3,000 square yards, that is to say, not far short of three-quarters of an acre.

There is to-day an army of microscopists engaged throughout the world in this branch of metallurgical work and research. In the aggregate there are doubtless hundreds of thousands of photomicrographs prepared each year to help in studying the structure of steel products for the guidance of both producer and user. It is impossible to exaggerate the importance of metallography as an adjunct in metallurgical research, or to over estimate the debt of gratitude due to Sorby. Though this is now generally realised it was not always so. As pointed out by Professor W. C. Fearnsides, M.A., F.G.S., when Sorby presented his first famous paper on microstructure to the Geological Society of London on December 2nd, 1857, he was received with general and freely expressed incredulity. Nevertheless:

> "Smiled at by Professor Tennant when beginning the speech, jeered at by his friend Leonard Horner (Vice-President of the Geological Society) who, at the meeting to which the results were presented, remarked from the chair that he had been a Member of the Geological Society ever since its foundation, and during the whole of that time he did not remember any paper having been read which drew so largely on their credulity, Sorby lived on to have those same results acknowledged and to be acclaimed by the geologists of all nations, assembled to celebrate the Centenary of the Foundation of the Geological Society of London, as the founder of modern Petrology."

Sorby's first work on the microscopical study of metals was in 1863. In 1864 he lectured on this topic in Sheffield, later in the same year communicating his results to the Bath meeting of the British Association.

The author well remembers in 1886 taking some of his first specimens of manganese steel to Dr. Sorby in order to ask his views with regard to the microstructure of this curious alloy

Camera Portrait by E. O. Hoppé.

W. H. Bragg.

of iron and manganese. Dr Sorby was not, however, able to report in this respect any special characteristics that would throw light upon this non-magnetic material with its many peculiar physical properties.

It was in 1885 that Dr. Sorby first showed the true composite nature of the "pearly constituent" of steel, as an aggregate of parallel plates. This discovery was the earliest recognition of the formation of crystals from a solid solution, and may be considered as the crowning achievement of his microscopical research. It was announced to the Iron and Steel Institute in 1886, and in 1887 in his paper on "The Microscopical Structures of Iron and Steel." Soon afterwards, these discoveries appeared to be the signal for great activity in the metallographic field, which he had so brilliantly started to explore.

It is not always possible to show who is the real originator and discoverer of new lines of thought. In this case, however, the pioneer's honour in leading the way in the study of the microstructure of metals is due to Dr. Sorby, and to him alone.

Happily, the mantle of Sorby as regards microscopy fell upon young and able shoulders in Sheffield, and Arnold, who has continued and greatly enlarged this important science, was for many years in close touch with the great master Sorby, of whom Sheffield is rightly so proud.

High-speed and Colour Cinematography.—Although cinematography presents itself mainly to us as a means of entertainment, it is worthy of special attention, both on account of its possibilities as a scientific aid and also as being in itself a most interesting application of scientific principles. Many workers are engaged in the improvement of this branch of technology. To the scientific investigator the means of following very rapid movements, which would be provided by an ultra-rapid cinema in convenient form, would be of considerable value, specially, for example, in examining dynamic problems, and in cases apart from rotating machinery where stroboscopic methods have been successfully applied.

Already with the Heape and Grylls rapid cinema, pictures have been taken by Mr. Walter Heape, F.R.S., at the rate of 5,000 per second. At this speed the film is driven at the rate of just over four miles per minute; this means driving a drum 6 ft. diameter, 1,000 r.p.m. and the two 10 in. diameter lens wheels, with 40 lenses in each wheel, 7,200 r.p.m. This naturally involves a heavy machine, weighing over three

tons, requiring for its housing a structure about 12 ft. by 6 ft. by 10 ft. Records taken by this means of quite simple mechanical operations have shown clearly that in some cases the succession of events is often very different from what would be supposed. Mr. Heape says it is quite possible to construct a machine which would take photographs with *f*4 lenses at the rate of 10,000 per second, while if *f*2 lenses were used the rate would be increased to, say, 30,000 per second. It is hoped some day with this apparatus to catch an armour-piercing projectile at work perforating an armour plate, which might teach us many new facts. Results of some promise have already been obtained.

In quite another direction the problem of reproducing subjects in their natural colours has received considerable attention. The results to be achieved in this way are much more than a mere pleasing effect to the eye, although the enhanced effects obtained in this way have been very marked. The author recently had the pleasure of seeing some colour cinema pictures produced by a new process invented by Mr. Friese-Greene. Excellent results are produced by the use of only two colours, although the process lends itself to the use of three or more colours. This, however, while adding very considerably to the cost, does not result in a commensurate improvement. The normal process results in a film in which alternate pictures are of the two separate colours, which become blended by the persistence of vision in the eye, and apparently without any bad effects due to eye strain. It is claimed that such films can be produced at a cost not very much exceeding that of the ordinary black and white type.

It would be possible, did space permit, to go on multiplying examples of the remarkable work now being done in science and engineering, but enough has been said perhaps to sketch the rise of science in this country, and to show the rapid and brilliant advance which ultimately arises from the laborious and tedious work of the pioneer. Before concluding this introductory section of the book, however, it seems desirable to controvert the oft-expressed opinion that the advance of science is making us ever more materialistic.

Science and Religion.—There is still deep down in the minds of many the feeling that science is inimical and antagonistic to religion. The best answer to this is the fact that religion—using the term with reference to no particular

creed—has now a firmer and more substantial hold than ever upon the minds of civilised human beings.

The lives of innumerable men of science, whose creed concerning mundane matters is to test every assertion and to worship facts, show that they find nothing incompatible between religious faith and scientific inquiry. This is admirably expressed by a noble and earnest passage at the end of Faraday's *Researches in Chemistry and Physics* which I quote from Mr. W. L. Randell's recently published book "*Michael Faraday.*"

> "I believe," says Faraday, "that as man is placed above the creatures round him, there is a higher and far more exalted position within his view; and the ways are infinite in which he occupies his thoughts about the fears, or hope, or expectations, of a future life. I believe that the truth of that future cannot be brought to his knowledge by any exertion of his mental powers, however exalted they may be; that it is made known to him by other teaching than his own; it is received through simple belief of the testimony given. Let no one suppose, for an instant, that the self-education I am about to commend, in respect of the things of this life, extends to any considerations of the hope set before us, as if man by reasoning could find out God. It would be improper here to enter upon this subject farther than to claim an absolute distinction between religious and ordinary belief. I shall be reproached with the weakness of refusing to apply those mental operations which I think good in respect of high things to the very highest. I am content to bear the reproach . . . I have never seen anything incompatible between those things of man which can be known by the spirit of man which is within him, and those higher things concerning his future which he cannot know by that spirit."

The author would like to quote also from one of the recent and excellent Research Narratives issued by the Engineering Foundation on this subject. The following words are taken from their Research Narrative No. 63, based upon a statement formulated by Dr. Robert A. Millikan, Director of Norman Bridge Laboratory of Physics, California Institute of Technology, and signed by thirty-five leaders in religion, science, and affairs. These men live in many parts of the United States and have diverse religious, scientific and business interests. The full statement and the names were printed in *Science*, June 1st, 1923:

> "The purpose of Science is to develop, without prejudice or preconception of any kind, a knowledge of the facts, the laws and the processes of nature. The even more important task of religion, on the other hand, is to develop the consciences, the ideals and the

aspirations of mankind. Each of these two activities represents a deep and vital function of the soul of man, and both are necessary for the life, the progress and happiness of the human race."

In the preceding pages it has been attempted to trace some of the main events and lines of progress of science. The meaning of the word science, from *scientia*—knowledge, and *scire*—to know, shows its object, that is to ascertain the Truth. To stimulate a wider and deeper interest in science is thus a worthy aim, for it is synonymous with a keener interest in Truth which is mighty and must prevail. As Milton has rightly said: "Who ever knew Truth put to the worst in a free and open encounter."

PART II—METALLURGY.

CHAPTER IV

THE IMPORTANCE AND ANTIQUITY OF IRON.

Siderology—The branch of science which we now call metallurgy was formerly known as "siderology," and the French equivalent of this term is still used in France, where the leading Metallurgical Association is known as the Comptoir Siderurgique. In this country the word "siderology" is obsolete, but "siderite" is still used as a name for magnetic iron ore, and "siderography" refers to engraving on steel.

The derivation of all these words is from Sidus, a star; a group of stars; a constellation; a sky; the heavens. It seems possible, therefore, that the term siderology was adopted in order to convey the idea that iron came from the stars in the form of meteorites of ferrous character, which are believed to have bombarded us in the early stages of the world's history. This theory has been put forward by several well-known authorities, and though it is probably only a partial explanation, it is certainly curious to find that, apart from known meteoric specimens, iron ore deposits exist on the surface of the earth or only at shallow depths.

The names of the two shepherds Sidère and Sidérite, the heroes of the beautiful poem "Ferrum" which forms Appendix I, are clearly derived from the same root as "siderology."

The Importance of Iron.—Though the modern term metallurgy includes the working of non-ferrous as well as ferrous metals, it is proposed here to deal mainly with iron and its alloys. Considerations of space make it impossible to deal with non-ferrous as well as ferrous metallurgy and preference is given to the latter, because it is the subject with which the author has been most intimately associated during the past forty years.

A remarkable prediction concerning the importance of iron

was made nearly 300 years ago by Joseph Glanvill, Prebendary of Worcester, who was one of the leaders of thought at that time. He was, in fact, one of the early Fellows of the Royal Society, being admitted in the year 1664. Speaking of the great and wonderful metal "Ferrum," Glanvill said:

> "Iron seemeth a simple metal, but in its nature are many mysteries, and men who bend to them their minds shall, in arriving days, gather therefrom great profit, not to themselves alone, but to all mankind."

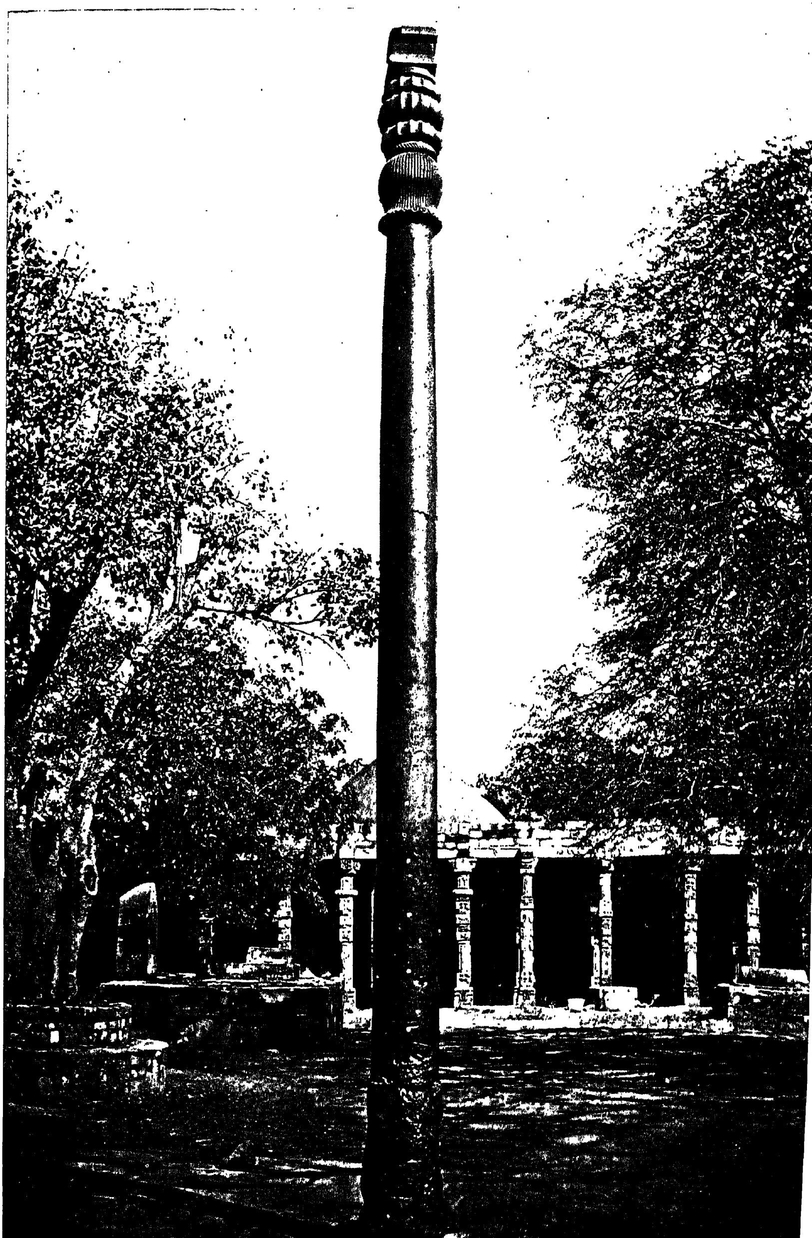
Indeed a prophetic utterance from so far back as 1650.

Iron has been, and will undoubtedly continue to be, of the highest profit to the world. Its study will always be a fascinating one, and if our knowledge of it progresses as much in the future as in the past, then the advance will be even more marvellous. It may unhesitatingly be claimed that iron is by far the most important metal to civilisation. The entire absence of what we call the precious metals, gold and silver, would but little affect our comfort or the applications of engineering and metallurgy; but take away iron and we should revert to the conditions of the Dark Ages.

Iron is, of course, essential to the manufacture of alloy or "special" steels which, as will be shown later, offer greater possibilities than iron itself or simple carbon steels.

The Antiquity of Iron.—In order to obtain a correct perspective of the early developments in alloy steels, and thus a clear conception of what has now been accomplished and of what still remains to be done, it is necessary to refer briefly to some of the events in the history of iron.

Iron has undoubtedly been used by man for more than two thousand years—as witness the fact that Aristotle (384–322 B.C.) described the manufacture of Indian steel. How much farther back the history of this metal extends into the mists of antiquity cannot be said definitely, but Percy stated in his classic book "Metallurgy: The Art of Extracting Metals from their Ores and adapting them to various purposes of Manufacture," that the Iron Age preceded the Bronze Age. He admitted that there had not been much evidence of this collected, but pointed out that this was largely due to the fact that iron is rapidly corroded by oxidation, even in dry climates; whereas bronze is acted upon but slowly, even in moist climates. As an indirect confirmation of this, Sir William Flinders Petrie, F.R.S., showed



THE DELHI IRON PILLAR.

Reproduced by courtesy of the Council of the British Wrought Iron Associations.

the author some time ago a small dagger-shaped knife, which he vouched for as dating back to the VI–VIII Dynasty, about 4000 B.C. But for the natural process of rusting we should, probably, have many more evidences on this point. The use of steel is attested by the mortuary furniture on many Anglo-Saxon graves. Many tombs of ancient times have revealed specimens of steel. Its comparative rarity is explained by the indifference with which it has been regarded by archæologists. Many specimens have been found accompanied by flints, the latter much worn by continued striking, and covered with oxide of iron, showing they had been in full use. These examples further confirm Dr. Percy's belief as to the position in point of time of the Iron Age. This fascinating subject has been dealt with at greater length in several of the author's papers before Scientific and Technical Societies, as mentioned in Appendix III.

Stephen Laing in his "Human Origins" points out that iron was no doubt known at a very early period, but it was extremely scarce, and even as late as Homer's time was stated to be so valuable that a lump of it constituted one of the principal prizes at the funeral games of Patroclus.

The antiquity of iron is shown in a valuable paper on "Iron in Ancient Egypt," by Mr. J. A. Wainwright in the Cairo "Scientific Journal," August, 1914. He refers to known specimens of iron found in the inner joints of the Great Pyramids—pickaxes, spearheads, ferrules, sickles and a helmet. Whence this metal was obtained, he states, is a most difficult question to answer.

Wainwright also points out the particularly interesting fact that the name of iron in Ancient Egypt was a strange one, for it was called the Stone of Heaven, and the name by which this metal was known in Ancient Babylonia was "Ana-bar," also meaning Stone of Heaven. This probably indicates the then rarity of iron and surely, too, that meteorites furnished in those very early days one, at any rate, of the sources of the metal.

In the author's papers on "Sinhalese Iron and Steel of Ancient Origin," read before the Royal Society, also the Iron and Steel Institute, in 1912, details will be found of his experiments with regard to the composition of ancient specimens of iron, including those taken from the actual Iron Pillar at Delhi. This remarkable column, illustrated in Plate XII, was probably made about A.D. 300. It is nearly pure iron,

24 feet in length and $6\frac{1}{2}$ tons in weight, and it is one of the finest specimens of ironwork produced until modern times; indeed, it is only within the last century or so that any European ironmaster could have undertaken to produce such a forging. The only explanation of this wonderful specimen of iron is that it must have been welded together in sections, though there are no signs of this on the pillar itself. The author had the great privilege of being able to obtain at considerable risk, from a friend in India, an actual specimen from this pillar, which is regarded by the natives as an object of worship. It was found to have the following composition:

C	Si	S	P	Mn	Fe	Sp.G.	
0·080	0·046	0·006	0·114	Nil.	99·720	7·81	%

Brinell ball hardness number 188

Iron in Mythology and Literature.—As might be expected from a metal which has been known and used since the earliest days of civilisation—and has, indeed, contributed fundamentally to the rise of civilisation—iron has figured largely in mythology and in the works of poets of all ages.

Campbell says that amongst the Scythians the iron sword was a god. It was the image of Mars and sacrifices were made to it. Vulcan was a smith; Thor wielded a hammer; even Fionn had a hammer which was heard in Lochlann when struck in Eirinn.

Smiles mentions that the weapon of bronze was dull; but that of steel was bright. The "white sword of light," one touch of which broke spells, liberated enchanted Princesses and froze Giants' marrow, King Arthur's magic sword "Excalibur," was regarded as almost heroic in the romance of chivalry. This famous steel sword was afterwards sent by Richard I as a present to Tancred; the value attached to the weapon may be estimated by the fact that the Crusaders sent the English monarch, in return for it, "four great ships and fifteen galleys."

Neither should we forget the work of Weland the Smith, Weland being the Scandinavian word for Vulcan, about whose name, as an ancient worker in metals, clusters so much traditional glory.

Chaucer, in his "Canterbury Tales," said of one of his

characters "A Shefeld thwytel bare he in his hose," showing that nearly six hundred years ago Sheffield cutlery was well known and esteemed.

In the works of our great poet Shakespeare, there are abundant metallurgical references. Wide as were his understanding and acquaintance with the world, there is good reason for giving him a special place, even in connection with so specific and technical a subject as metallurgy. Although he may not have been a worker in this branch of science, it is evident from the information and quotations given below that he had more than a passing knowledge of, and interest in, the metal iron and its applications.

Some time ago, when staying at Stratford, the author visited the Shakespeare Memorial Library, then in charge of Sir Oliver Lodge's brother, Mr. Ernest Lodge, who made it possible to investigate whether Shakespeare, with propriety, might be said to have been interested in metallurgy. The result was that many references were found. Also, the well-known Shakespearean scholar, Sir Sidney Lee, was kind enough to look into the subject and found an interesting reference to a mysterious Overseer and Legatee under Shakespeare's will, who was interested in metallurgy.

This legatee and friend, Thomas Russell, alone of all the persons mentioned in the will of Shakespeare, bore the dignified designation of "Esquire." He received £5, and was also nominated one of the two Overseers, Francis Collins being the other. There is no proof in the local records that Russell was a resident in Stratford, and he was in all probability a London friend. It was known that Shakespeare had opportunities of meeting him in London, and, in the dramatist's later life, Russell enjoyed a high reputation there as a metallurgist, obtaining patents for new methods of extracting metals from the ore, including making and extracting of copper out of copper ores and other mineral substances; making of brimstone and Danske copperons; making copper out of any copper mines within England and Ireland; working and making of copper by a new way of dissolving the ores in water or liquor. Full particulars of these patents granted in the years 1609, 1610 and 1614, can be seen at the Public Record Office, Chancery Lane.

As early as 1608 Sir Francis Bacon was seeking this same Thomas Russell's acquaintance on the double ground of his

scientific ingenuity and his useful influence. It is stated that Shakespeare owed to Drayton the acquaintanceship with Russell, which Bacon also aspired to share. Shakespeare was probably, therefore, interested in the affairs of his friend Russell, and no doubt discussed with him metallurgical subjects of the times. He seems often to have visited Birmingham, and seen its metallurgical activities.

Another and particularly curious instance as to the Poet's interest in iron is that mentioned to the author by Mr. F. C. Wellstood, M.A., Secretary and Librarian to the Trustees and Guardians of Shakespeare's Birthplace and Deputy Keeper of the Records of Stratford-on-Avon. He states that among the exhibits in the Birthplace Museum is a document witnessed by the dramatist's father, concerning his neighbours in Henley Street in 1575. It is a deed of sale by William Wedgewood, of Stratford, *tailor*, to Edward Willes, of Kyngsnorton, yeoman, for £44, of two tenements in Henley Street occupied by Wedgewood, "betwyne the tenement of Richard Horneby, *blacksmith*, of the east part, and the tenement of John Shakesper, yeoman, of the west part," 20 Sept., 1575. Among the witnesses are John Shakesper and Richard Horneby.

Shakespeare was eleven years old at the date of this deed, and his father's house where he resided was next door to that of William Wedgewood, the *tailor*. The forge and smithy of Richard Horneby adjoined Wedgewood's shop. Horneby's premises now form the Birthplace Ticket Office.

Horneby's forge and smithy must have been frequently visited by the poet in his boyhood days, and no doubt suggested to him later on in life the vivid picture which he gives in *King John, iv*, 2, 193 :

> "I saw a *smith* stand with his hammer thus,
> The whilst his iron did on the anvil cool,
> With open mouth swallowing a *tailor's* news ;
> Who with his shears and measure in his hand,
> Standing on slippers,—which his nimble haste,
> Had falsely thrust upon contrary feet."

In view of the statement made by Mr. Wellstood, as to the Horneby Forge and Smithy being next door to the house where Shakespeare lived in his boyhood days, the references in these lines to the "smith" and the "tailor" are of peculiar and apposite interest. How vividly are brought before us the brawny smith acquiring news from the gossiping tailor ! Moreover, as a friend points out, this little instance proves in a

striking manner that the man who uttered these words was certainly not Bacon, or some other individual, but William Shakespeare himself, who had seen and known the smith and tailor so graphically described.

In his various plays, Shakespeare makes reference to iron about forty-eight times; to steel, sixty-four times; gold, one hundred and twenty-one times; silver, fifty-four times; also to fire and fuel, a considerable number of times. Copper is mentioned only four, and brass fourteen times. There are also many indirect references of metallurgical nature, the following being probably some of the most interesting ones:

> "Are you more stubborn-hard than hammer'd iron."
> *King John*, Act IV, Sc. I.
>
> "Then join you with them, like a rib of steel to make strength stronger."
> 2 *Henry IV*, Act II, Sc. III.
>
> "When steel grows soft as the parasite's silk."
> *Coriolanus*, Act I, Sc. IX.
>
> "Here is now the smith's note for shoeing and ploughing iron."
> 2 *Henry VI*, Act V, Sc. I.
>
> "I'll leave thee now like a man of steel."
> *Antony and Cleopatra*, Act IV, Sc. IV.
>
> "My desire more sharp than filed steel, did spur me forth."
> *Twelfth Night*, Act III, Sc. III.
>
> "As true as steel."
> *Troilus and Cressida*, Act I, Sc. III.
>
> "Whose golden touch could soften steel and stones. Make tigers tame."
> *Two Gentlemen of Verona*, Act III, Sc. II, 79.
>
> "With hard bright steel and hearts harder than steel."
> *Richard II*, Act III, Sc. II.
>
> "Strong-tempered steel his stronger strength obey'd."
> *Venus and Adonis*.

How strikingly, too, does Shakespeare appeal to the metallurgist, whether ferrous or non-ferrous, when he says:

> "Roast me in Sulphur; wash me in sleep down gulfs of liquid fire."
> *Othello*, Act V, Sc. II.

To those who have handled "gulfs of liquid fire," whether from the blast furnace, the Bessemer and open hearth steel melting shops, or the electric furnace of still later origin, this is a striking allusion to certain well-known characteristics of the calorific side of our science, in which both ferrous and non-ferrous investigators can heartily agree.

From all this evidence, internal and external, it will be seen that Shakespeare was undoubtedly interested in metallurgy, and he might fairly have been elected Honorary Member of the Iron and Steel Institute and the Institute of Metals had these institutions then existed !

One of the finest poetical conceptions regarding the metal iron is to be found in the fascinating Latin poem "Ferrum," composed in 1717 by Le Prêtre Xavier de la Sante, a Jesuit Professor of Rhetoric at the College of Louis le Grand, Paris. A copy of this, together with his own rendering in French, "Le Fer," was sent to the author in 1906 by his personal friend, the renowned French metallurgist, the late Professor Floris Osmond. An English translation of this poem, prepared for the author by Mr. L. P. Sidney, is given in Appendix I.

A bronze group embodying the poetical ideas so beautifully expressed by Father Xavier de la Sante is shown in the Frontispiece of this book. The execution of this commission was carried out by Mr. Frederick J. Halnon, R.B.S., and the group was exhibited at the Royal Academy in 1923. As a slight appreciation of many kindnesses received over a long period of time from numerous French scientists, including metallurgists and engineers, it has given the author much pleasure to present a replica of this group to the Conservatoire des Arts et Métiers, Paris, where his friend Dr. Léon Guillet is Professor of Metallurgy.

Early Metallurgists and Metallurgical Literature.—Whilst iron was known so early in the history of mankind, it was not until comparatively recent times that its production on a large scale was commenced, using coal in place of charcoal for smelting. As already mentioned, Dud Dudley, in 1619, was probably the first to smelt iron with "pit-coale" on a scale which was then considered quite large and important industrially.

The annotated list of early workers in scientific metallurgy, presented in Appendix II, may be found useful for reference. In considering the results which these and other early workers obtained, they must be judged according to the knowledge prevailing and the facilities existing at the time concerned. In 1722 Réaumur published an important treatise on the conversion of bar iron into steel, and described cementation furnaces very much like those still in use, as well as a method for annealing hard iron castings by heating them when embedded in iron ore. Réaumur was, however, largely responsible for

the mistaken idea, prevalent amongst French metallurgists for a century or more, that the irons made in France could be treated—with the imperfect resources then available—so that they would equal the pure products of Sweden. The retarded progress resulting from this failure to appreciate the limitations of materials and methods then available may, perhaps, still convey a useful warning. It emphasises also the difficulties which beset the early workers in any field of research, for the ores which gave a definitely inferior product in the eighteenth century can, in the present state of our knowledge and equipment, be made to yield steel of the highest quality. Similarly, with the materials and other resources available forty years ago, it was immeasurably more difficult than it is to-day to make alloys of any desired composition.

The carbon steels made by the armourers of the Middle Ages were often as good as the best steels that can be produced to-day without using special alloys, but the knowledge then available was of a purely empirical nature. In the course of generations, methods had been evolved whereby the best results could be obtained from the resources available. In relation to our present-day knowledge, the armourer working with carbon steels and the Mushets working with self-hardening alloy steel occupied the same plane of successful empiricism.

It is not always realised how much the subsequent progress of metallurgy was facilitated by the great work done in Sweden during the seventeenth and eighteenth centuries in the discovery and isolation of many of the elements now used for alloy steels. Thus G. Brandt discovered cobalt in 1733; Axel Frederic Cronstedt discovered nickel in 1751; Karl Wilhelm Scheele (1742–1786) discovered manganese, molybdenum, and other elements; and Jons Jakob Berzelius (1779–1848) isolated silicon, and was the originator of the theory of allotropy; Martin Heinrich Klaproth (Germany) discovered uranium in 1789, and titanium in 1794; Fausto de Elhuyar (Spain) was the first to prepare metallic tungsten (1792); and Louis Nicolas Vauquelin (France) discovered chromium in 1797.

Though chemists of other countries discovered these important metallic elements, British workers have not been idle. Indeed, the work of Robert Boyle, Isaac Newton, Benjamin Huntsman, Abraham Darby, Joseph Priestley, Henry Cort, John Dalton, Humphry Davy, Michael Faraday, David and Robert Mushet, Henry Bessemer, William Siemens,

Lowthian Bell, George Snelus, Sidney Thomas, Percy Gilchrist, and others—to say nothing of those belonging to a period nearer to our own times—contributed greatly to the state of chemical and metallurgical knowledge at the middle of last century. Nevertheless, despite the labours of such pioneers as Agricola (Germany), Dud Dudley (England), Pettus (England), Swedenborg (Sweden), Huntsman (England), Rinman (Sweden), Cronstedt (Sweden), Bergman (Sweden), De Elhuyar (Spain), Vauquelin (France), Heath (England), Mushet (England), Berzelius (Sweden), Berthier (France), Percy (England), and Faraday himself, who carried out important experiments of great promise on alloys of iron with other elements, it was not until the decades 1870 to 1890 that there occurred the great advances and tremendous burst of activity in metallurgical science, of which we see the striking results and benefits to-day.

The quality of the literature of a particular branch of science generally shows the relative position it occupies in the world, and this is well illustrated by the science of metallurgy.

The author has been fortunate in getting together a collection of some three hundred books on metallurgy, chiefly old, dating from about A.D. 1400 down to the present time. The following are the names of the chief writers on the subject between 1546 and 1880, that is, a period of over 300 years.

Agricola	1546	David Mushet	1840
Dud Dudley	1665	Faraday	1842
Sir J. Pettus	1683	Heath	1856
Réaumur	1722	Percy	1861
Swedenborg	1734	Holley	1865
Jars	1774	Whitworth	1866
Bergmann	1778	Kohn	1869
Rinman	1782	Osborn	1869
Cronstedt	1788	Crookes	1870
Berthollet	1789	Röhrig	1870
Vauquelin	1808	Gruner	1872
Karsten	1824	Greenwood	1874
Berzelius	1833	Barba	1875
Berthier	1834	Ledebur	1877
Jeans	1880		

It will be seen that even as late as 1870, only half a century ago, such literature was meagre indeed, and it can safely be said that hardly any of the books published before 1870 would be of the slightest practical value to-day, so rapid has been the advance and so great the gain in our knowledge.

In those days, metallurgists simply did not know and had

but little scientific guidance of any kind. It was the day of rule of thumb. Beyond Percy's admirable treatises and one or two others, books of value on ferrous metallurgy were few and far between, neither were there any technical societies in this country or elsewhere dealing with this branch of science until 1869, when the Iron and Steel Institute was founded.

Metallurgy has now a wide range of scientific literature dealing with the ferrous and non-ferrous sides respectively, all helping on our knowledge.

There are, too, the British Iron and Steel Institute, with nearly three thousand members, the American Iron and Steel Institute, the American Institute of Mining and Metallurgical Engineers, with probably ten thousand members, the British and American Institutes of Metals, and other Anglo-Saxon bodies dealing with metallurgy, to say nothing of smaller societies here, in France, Belgium, Italy, Sweden, Germany, Austria, Russia and elsewhere. There are, therefore, to-day tens of thousands of members of the profession devoting attention to scientific and practical metallurgy, and all this has been done in the short space of time represented by but half a century.

According to the *Mechanic's Encyclopædia* published in 1835, the output of pig-iron in the United Kingdom in 1740 was 17,000 tons made by 59 furnaces; in 1788 the output was 68,000 tons from 121 furnaces; and in 1827 it was 690,000 tons from 284 furnaces. As a contrast it may be mentioned that there are now at work in the United States blast furnaces of such large dimensions that they produce about 300,000 tons annually. Two of these furnaces would turn out almost as much as the whole output of the 284 furnaces used in 1827. This shows the wonderful strides made by the metallurgist during the past hundred years.

It is, however, during the past forty years that our knowledge of iron and its alloys has advanced with phenomenal rapidity and to a degree which few, if any, persons living fifty years ago would have deemed credible. Alloy steels, in particular, to which we owe so much to-day, were practically unknown at that date; the Mushets had developed self-hardening alloy steel, but, as shown by the metallurgical literature of the seventies, there was no scientific knowledge of alloy steels in the modern sense.

Eminent Metallurgists of Later Years.—Though it

is impracticable to give here the names of all those who have made the metallurgy of iron and its alloys what it is to-day, some of the more prominent workers are mentioned below, and references to others are given in later chapters of this book. Many of these, alas, have passed away, but their work will endure and their names should not be forgotten.

The late Sir Frederick Abel conducted a number of valuable researches, particularly in reference to carbon steels, and for these and other research work he received from the Iron and Steel Institute the much-prized recognition of the Bessemer medal. Both research and practical work on carbon and alloy steels, as regards their manufacture and composition, heat-treatment and metallographic examination, have been continued by many investigators, and in the list now presented the author refers chiefly to those who have been concerned and instrumental in dealing with the heat-treatment and metallography of alloy steels.

To the credit of Great Britain: there is the work of Sorby, Roberts-Austen, Stead, Riley, Vickers, Spencer, Arnold, Rosenhain, Carpenter, Desch, Hopkinson, Harbord, Sandberg, Turner, Talbot, Aitchison, Brearley, Hatfield, Dickenson, Edwards, and others. The United States can claim: Holley, John Fritz, Benneville, Egglestone, Raymond, Wellman, Hunt, Keep, Howe, Sauveur, Hibbard, Burgess, Campbell, Moldenke, Jeffries, Northrup, Stoughton, and Strauss. Famous metallurgists of France are: Brustlein, Osmond, Henri Le Chatelier, Schneider, Pourcel, Guillet, Guillaume, Dumas, Charpy, Frémont, Girod, Héroult, Moissan, Portevin, Robin, and others: whilst as regards other nationalities there must be mentioned: Ledebur, Martens, and Wedding; Giolitti, Akerman, Benedicks, Brinell, Westgren; Tschernoff, Belaiew; and Honda.

In the early days of the author's work in Sheffield he received much help and encouragement from his father, Mr. Robert Hadfield; the late Dr. Clifton Sorby, F.R.S.; Dr. W. M. Hicks, F.R.S.; Professor Ripper; the late Professor L. T. O'Shea; Professor J. O. Arnold, F.R.S.; Mr. T. Andrews, F.R.S.; and many others, including those to whom further reference is made in later chapters.

The world at large should be specially grateful to the band of scientific workers—amongst others, such men as Gore, Barrett, Hopkinson, father and son, Osmond, Roberts-Austen,

Arnold, Callendar, le Chatelier and Sauveur—who thought that the study of metallurgy was worthy of recognition. It is largely owing to their efforts that we have been able to progress so rapidly, and it is due to them that metallurgy no longer feels its way haltingly along the former dark paths of empiricism, but now advances with swift and certain steps, guided by the pure light of science. In fact, metallurgy has become a part of science.

CHAPTER V

CARBON IN SIMPLE AND ALLOY STEELS.

The Importance of Carbon in Iron Alloys.—The remarkable properties of the many special steels which have been produced since the discovery of manganese steel forty years ago have, to some extent, obscured the vitally important part played by carbon in the alloys of iron. Nevertheless, no treatise which sets out to review the development of alloy steels can fulfil its aim unless it deals with the influence of carbon in the alloys of iron. On this subject, which has roused so much contention, the author has advanced, during a period of many years, a mass of evidence which was presented in collected and summarised form in his paper on "The Development of Alloy Steels," read before the Empire Mining and Metallurgical Congress at Wembley in 1924.

The author has, on a number of occasions, pointed out the weaknesses of the allotropic theory and the improbabilities involved by the assumption that there is a β-form of iron. Carbon is the only metalloid which has been proved to confer water-hardening qualities on iron, and the effects of special elements on the hardness of alloy steels demand the presence of carbon and are due primarily to effects produced on the carbon and not on the iron.

The following words, contributed by the author to the first issue of *The Iron and Steel Metallurgist and Metallographist* twenty years ago, still hold good:

> "Notwithstanding the important part played by all these new iron alloys, carbon still maintains a very important position—in fact, a premier one, in determining the practical value of steel used for structural purposes. In other words, the practical value of various steel products is, for the major portion of their uses, obtained and determined according to the percentage of carbon present."

Carbon in Simple Steels.—The direct combination of carbon with iron as carbide of iron was fully proved by Dr

Sorby's invaluable microscopical researches. Professor A. Ledebur, of Freiberg, Professor Roberts-Austen, F.R.S., and Professor J. O. Arnold, F.R.S., also rendered great services to metallurgy by their various researches on the influence of carbon in iron.

In particular, Professor Ledebur's analysis of carbon steels* with the carbon classified as (1) hardening carbon, (2) carbide carbon, and (3) graphite and temper carbon, threw much light on the changes in the form of carbon which occur in the thermal treatment of simple steel.

Professor Roberts-Austen investigated most carefully the properties of a series of carbon steels, and his work showed the enormous effect of even small changes in the percentage of carbon on the properties of simple steel.

In a paper entitled "The Influence of Carbon on Iron," presented to the Institution of Civil Engineers in 1895, Professor J. O. Arnold, F.R.S., gave the results of an admirable series of investigations on eight steels containing from 0·08 to 1·47 per cent. of carbon and about 0·25 per cent. or less of impurities. The result of these classic investigations show perfectly the effects of carbon on all the main physical and mechanical properties of simple carbon-iron alloys.

Though the fact appears to be often overlooked, the mechanical properties of simple carbon steel can, by appropriate heat-treatment, be improved to a relatively greater extent than those of many alloy steels. There are, too, many applications in which properly treated carbon steel is quite as satisfactory as more costly alloy steel. One of these in which heat-treated carbon steel stands pre-eminent is in the manufacture of mining drills which may be required to penetrate the hardest and toughest rocks.

In this connection, reference may be made to Table II which shows the Brinell ball and scleroscope hardness numbers, and other physical and mechanical properties of various types of steel.

Carbon in Alloy Steels.—In the above-mentioned paper on "The Development of Alloy Steels" (Empire Mining and Metallurgical Congress, 1924), the author demonstrated the important effect of carbon in alloys of iron by presenting a

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* See "The Nomenclature of the Various Forms of Carbon Occurring in Iron," *Stahl u. Eisen,* Nov. 1888; and "Recent Experiments on Carbon and Iron," *ibid.,* April, 1891.

TABLE II.

COMPARATIVE TABLE PREPARED BY THE AUTHOR, SHOWING THE RELATION BETWEEN BRINELL BALL ALSO SCLEROSCOPE HARDNESS NUMBERS AND COMPRESSION STRENGTH, YIELD POINT, TENACITY, FRÉMONT AND IZOD SHOCK QUALITIES OF VARIOUS TYPES OF STEEL.

This table represents the average of a large number of tests on all types of steel, and is intended as an approximate guide. Individual results must necessarily vary considerably from the average.

ZONES OF HARDNESS F TO A	APPROX. SCLEROSCOPE HARDNESS NUMBER.	BRINELL BALL HARDNESS NUMBER.	SHOCK QUALITIES.						TENSILE STRENGTH.				COMPRESSION. On specimens ·564″ diameter and ·70″ in height.		
			AVERAGE FRÉMONT TEST.			AV'R'GE IZOD TEST.	BASED ON	EXAMPLES.	YIELD POINT.		MAXIMUM STRESS.		ELASTIC LIMIT AND ·25% COMPRESSION.		COMPRESSION % (100 tons per sq. in.) (163 Kilogrammes per sq. m/m.)
			Kilogrammes.	ft. lbs.	Angle of Bend in degrees.	ft. lbs.			Tons per sq. in.	Kilogrammes per sq. m/m.	Tons per sq. in.	Kilogrammes per sq. m/m.	Tons per sq. in.	Kilogrammes per sq. m/m.	
F	19 23 27 30 34	100 125 150 175 200	16 13	115 to 95	70° 50°	80 to 55	Carbon Steel.	Forged Mild and Medium Hard Steel.	13 17 21 26 32	21 27 32 41 50	26 31 36 41 46	41 49 57 65 72	13 15 17 19 21	21 24 27 30 32	64·0 55·0 47·0 40·0 35·0
E	38 42 46 50	225 250 275 300	13 7	95 to 51	50° 23°	55 to 23	Alloy Steel, e.g., Nickel Chromium Steel quenched and tempered.	50/60 ton Alloy Steel for Bars, Forgings, etc.	38 44 50 55	60 69 79 87	51 56 60 64	80 88 95 101	23 26 30 34	36 41 47 54	31·0 27·0 23·0 19·0
D	54 57 61 64	325 350 375 400	7 3·5	51 to 25	23° 4°	28 to 12		60/70 ton Alloy Steel for Crankshaft. 70/80 ton Alloy Steel for Connecting Rod Forgings.	61 67 73 79	96 105 115 124	69 74 79 86	109 117 124 135	38 43 49 55	60 68 77 87	15·2 11·3 8·0 5·6

C	68 71 75 78	425 450 475 500	3·5 2·5	25 to 18	4° 2°	12 to 8	Alloy Steel, e.g., Nickel Chromium Steel quenched and tempered.	100/120 ton Alloy Steel for Gears.	85 92 99 105	134 145 156 165	92 100 107 115	145 158 169 181	61 67 74 81	96 105 116 127	3·8 2·4 1·3 0·6
B	80 84 86 89	525 550 575 600	2·5 1·5	18 to 11	2° 1°	8 to 4		120 ton Alloy Steel. Dies for Cold Stamping, etc.	111 118 125 132	175 186 197 208	122 130 137 145	192 205 216 228	87 94 101 108	137 148 159 170	0·23 0·21 0·20 0·18
A	92 95 99 101	* 625 650 675 700	Below 1	Below 7	Below 1°	Below 3	Carbon or Alloy Steel.	Hardened material of various Types.	139 146 153 160	219 230 241 252	152 160 169 178	239 252 266 280	115 122 129 136	181 192 203 214	0·16 0·14 0·13 0·12
A 2 Owing to want of data, but little is known about this extremely high zone of "super-hardness."	— — — —	725 750 775 800	Not definitely Determined.				Carbon or Alloy Steel.		Not definitely Determined.		Not definitely Determined.		144 151 159 166	227 238 250 261	0·11 0·9 0·8 0·7

* Glass scratching hardness commences here.

The printed capital letters in the zone column refer to special sections of zones of hardness as follows:—

Zone.	Brinell Ball Hardness Number. From	To	Scleroscope Hardness Number. From	To	Yield Point. Tons per sq. inch. From	To	Maximum Stress. Tons per sq. inch. From	To
F	100	200	19	34	13	32	26	46
E	200	300	34	50	32	55	46	64
D	300	400	50	64	55	79	64	86
C	400	500	64	78	79	105	86	115
B	500	600	78	89	105	132	115	145
A	600	700	89	101	132	160	145	178

Conversion Table of work required to fracture Nicked Frémont and Izod Specimens.

Ft. Lbs.

Frémont	4	7	14	22	29	36	43	50	58	65	72	108	145	180	217
Izod ...	2	4	7	10	13	18	26	34	41	46	51	68	80	110	130

Hardness of Microconstituents, Carbon Steel with Fe as unity.

	Sclerometer Tests.	Brinell Ball Number.
Ferrite	1	82
Pearlite	4·3	196
Sorbite	5—54	332
Troostite	88	444
Austenite	103	204
Martensite	39—262	196—700
Hardenite	239	700
Cementite	273	Not determined.

selection of data from researches extending over many years. This information is now reproduced on account of its intrinsic interest and because it cannot be emphasised too frequently or too strongly what an important part carbon plays in determining the qualities of all steels.

One of the early demonstrations of the important effect of carbon in alloys of iron was in relation to the properties of silicon-iron alloys. At one time it was commonly believed that more than 0·1, or 0·2 per cent., at most, of silicon was highly injurious to steel which had to be used in its forged state. In the author's paper " On Alloys of Iron and Silicon " (Iron and Steel Institute, 1889) it was shown, however, that the mechanical unreliability of alloys containing carbon, silicon and iron, was due, not to the silicon *per se*, but to the combination of silicon with carbon and iron. Provided that carbon is absent, or present only in small amounts, alloys of iron with silicon, up to what may be termed quite large amounts of silicon, give good tests as to malleability and toughness.

Similarly, a paper on " Alloys of Iron and Chromium," presented to the Iron and Steel Institute in 1892, includes the results of investigations carried out jointly by Professor Osmond and the author. These show conclusively that chromium *per se* does not harden steel, but that its hardening influence is indirect in nature and consists in " enabling the carbon present to act more energetically upon, and to combine more readily and intimately with, the iron." That this is so has been confirmed quite recently, for it has been found that on removing the carbon from rustless steel there is obtained a ductile, rustless iron.

As bearing upon the same point the unfortunate experience of the Tasmanian Iron and Charcoal Co. may be recalled. This company exploited chrome iron mines in the Ironstone Hills district, near the River Tamar, Port Lampriere, about fifty years ago, but the venture proved a failure owing to the chromium converting all the carbon present into the combined form. No other product could be obtained than a hard white pig-iron, which was of little use for foundry purposes and could not be puddled or made into steel, though as an alloy its use was found beneficial for special purposes. In fact, one of the Hadfield projectiles which was fired at Shoeburyness some twenty-five years ago, and which was one of the first cast-steel projectiles to perforate thick armour as then made, was produced

from steel containing chromium obtained by the use of the Tasmanian pig-iron described above.

The essential importance of carbon in alloy steels is shown very clearly indeed by the properties of specimens 73 and 73 J (Table III) prepared by the author in 1903. These steels were practically identical except as regards the percentages of carbon, but the amount of carbon in No. 73 J was about half of that in No. 73. Small as this distinction might appear, it made all the difference between a good tool steel and one which was quite useless for cutting purposes. Whereas steel No. 73 had a ball hardness of 255 before, and 565 to 760 after, heat-treatment, steel No. 73 J could not be properly self-hardened by cooling in an air-blast from white heat (1150° C.) and had then a ball hardness of about 160, compared with 202 for the same steel in the forged condition.

TABLE III.—TUNGSTEN-CHROMIUM ALLOY STEELS WITH DIFFERENT PERCENTAGES OF CARBON

Steel No.	Percentage Composition.						
	C	Si	S	P	Mn	Cr	W
73 . .	0·74	0·10	0·04	0·03	0·28	2·84	18·00
73 J . .	0·35	0·10	0·03	0·03	0·33	2·82	18·95

Each of these steels contains the same special elements, to an amount exceeding 20 per cent., and one of them containing 0·74 per cent. of carbon is high-speed steel of the usual satisfactory quality; whilst the other, containing 0·35 per cent. of carbon, is worthless for such a purpose. No clearer proof could be given of the importance of carbon in alloy steels.

Table IV shows the change in form of the carbon in steel No. 73, and the corresponding change in hardness of the metal, before and after heat-treatment. Initially, about 75 per cent. of the carbon was in the form of carbide carbon and the remainder in the form of hardening carbon—these terms being used as defined by Ledebur. After heat-treatment, when the nose of the tool was in the right condition for cutting, the proportions of carbide carbon and hardening carbon were nearly reversed. It must be recognised that the new properties acquired by the

hardened steel were due mainly to this change in the form of the carbon, the other elements of the alloy enabling the hard cutting properties of the steel, due to the hardening carbon, to be retained at temperatures which would soften ordinary steel.

TABLE IV

HARDENING AND CARBIDE CARBON IN HIGH-SPEED TOOL STEEL BEFORE AND AFTER HEAT-TREATMENT

Steel No. 73 (see Table No. III).	Before Heat-Treatment.	After Heat-Treatment.
Hardening Carbon	0·18 per cent.	0·60 per cent.
Carbide Carbon	0·56 ,,	0·14 ,,
Total Carbon	0·74 ,,	0·74 ,,
Ball hardness	255	565 to 760

For yet another proof of the remarkable importance of carbon in alloy steels, reference may be made to the paper on "Alloys of Iron and Molybdenum" which the author contributed to the Institution of Mechanical Engineers in 1915. Therein particulars are given of a series of carbon-molybdenum-iron alloys investigated by M. Guillet, and of a series of molybdenum-iron alloys with very low carbon content prepared and examined by the author. It appears that the carbon-molybdenum-iron series containing about 0·8 per cent. of carbon ceased to be forgeable when containing above 5 per cent. of molybdenum, whereas the author's nearly carbonless alloys of iron and molybdenum would forge up to 18·70 per cent. (and even higher) of molybdenum.

Metallurgical Equivalents of Different Elements.—The constituents of alloy steels, as revealed under the microscope and as determining the physical properties of the metal, are essentially those of carbon steel. In other words, though the chemical compositions of alloy steels differ widely from those of simple carbon steel, the main effect of the special elements is to enable the physical properties of carbon steel to be developed to a degree otherwise unattainable, or maintained under conditions which would alter them, were the special elements not present. The carbon in "alloy steels" is as essential as the special elements, though the percentage of the latter is often much higher than the percentage of carbon. Some effects of

the special elements cannot be explained as effects exerted upon the influence of the carbon, but, in regard to the effects of special elements in binary alloy steels (iron, carbon, and one special element), it is possible to trace a more or less definite relation between the percentage of the special element and the percentage of carbon.

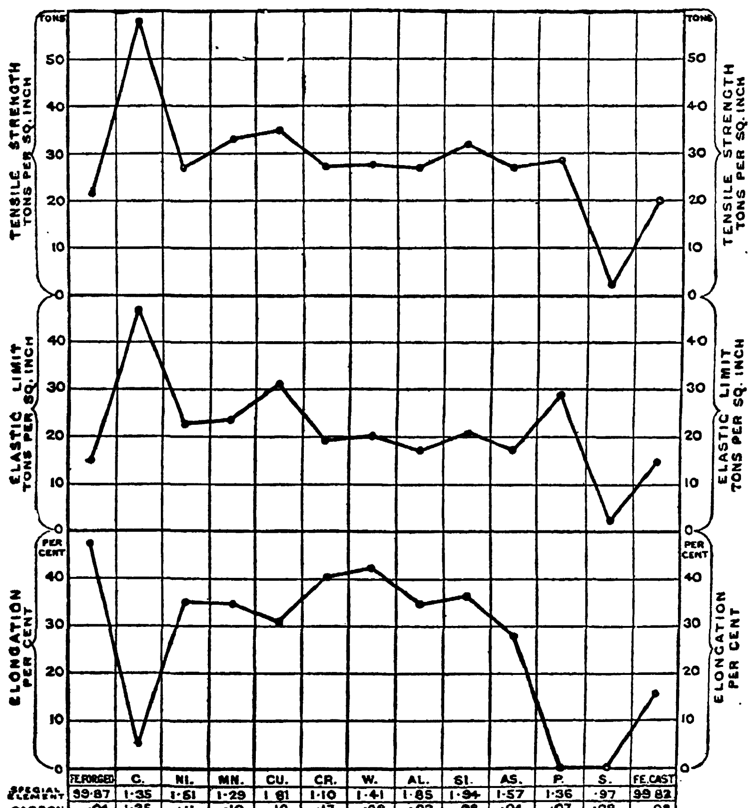


FIG. 1.—ARNOLD: PHYSICAL INFLUENCES OF ELEMENTS ON IRON.

In the words of Professor Osmond: "One fact, foreshadowed by Hadfield since his earliest beginning, was clearly evident, namely, that all the useful foreign substances added to iron had the effect of essentially modifying the iron itself and they might be substituted for one another, in equivalent proportions, not, it is true, without modifying to some extent the secondary

properties, but without altering abruptly the essential characteristics of the type—that was to say, and this was the chief point, that there were metallurgical equivalents for substances which, though widely differing numerically from the chemical equivalents, were nevertheless qualitatively analogous."

Valuable work carried out by the well-known French metallurgist Guillet confirms this view. He showed that the effect of increasing either the percentage of carbon or the percentage of the third element, in an alloy containing iron, carbon, and one special element, was to change the structure of the steel from a pearlitic to a martensitic, austenitic, or even cementitic nature or state. The greater the percentage of carbon, the smaller the proportion of the special element needed to produce a given change in structure and, conversely, the higher the percentage of special element, the lower the percentage of carbon needed.

A particularly interesting investigation into the relative effects of various elements when alloyed with iron was carried out by Arnold and described by him in a paper entitled "The Physical Influences of Elements on Iron," read before the Iron and Steel Institute, in 1894. A series of thirteen alloys was prepared, including cast and forged pure iron, also iron alloys containing respectively, as nearly as possible, 1½ per cent. of carbon, silicon, aluminium, manganese, nickel, copper, chromium, tungsten, arsenic, phosphorus, and sulphur. An exhaustive series of mechanical and microscopical tests was undertaken, offering a unique correlation. The author has plotted in Fig. 1 Professor Arnold's data relating to tensile strength, elastic limit, and elongation. While these tests do not give the effect of wide variations in the percentages of each element, they afford an interesting and valuable comparison of the effects produced by approximately the same percentage of different elements.

CHAPTER VI

THE RISE AND IMPORTANCE OF ALLOY STEELS.

Definition of "Alloy Steels."—Strictly speaking, all steels are alloys, for even "simple steel" contains up to 1·50 per cent. or more of carbon, which element has a greater effect than any other on the properties of iron. It is usual, however, to reserve the term "alloy steel" or "special steel" for steels which owe their properties to the presence of elements other than carbon, even though the carbon still plays a vitally important part in determining the characteristics of the alloy. This definition does not include as alloy steels those to which a small percentage of manganese, silicon, aluminium, titanium, or other element is added in order to eliminate objectionable constituents or mechanical defects, such as blow-holes, from carbon steel.

The Importance of Alloy Steels.—The importance of certain alloy steels, particularly manganese steel, silicon steel, high-speed tool steel, and rust-resisting steel, is so great that these materials are discussed individually in later chapters, but it seems desirable first to review broadly the general importance of alloy steels as a whole. In this matter the author can claim to have been a true prophet, for in a paper read before the Iron and Steel Institute as far back as 1892, he said :

> "The author cannot but think that the special question of steel alloys or combinations will be eventually found to possess considerable practical importance to the world at large, and perhaps be the means of eventually enabling our civil and mechanical engineers to design and carry out works of a magnitude which, notwithstanding the great strides made during the last few years, even at present are not possible."

The truth of this forecast, made thirty-two years ago, has since been demonstrated in the most convincing manner.

The Iron Age, which merged into the Steel Age when Bessemer and Siemens discovered their processes for manufacturing steel, has since developed into the Era of Special

Steels. Without iron we should inevitably revert to the impotence of the Dark Ages, and without alloy steels our fate would be little better, for iron and the simpler forms of steel will not give us, for example, the hard-wearing toughness of manganese steel; the wonderful energy-saving properties of silicon steel as used for electric generators, motors, and transformers; the greatly reduced rusting qualities of chromium and other steels; the special magnetic properties of tungsten and cobalt steels for permanent magnets, and of manganese steel for applications where non-magnetic material is required; also the nickel-iron alloy known under the term "Permalloy," with its extraordinary high permeability at low induction. In addition, there are steels which are strong and tough at low temperatures, steels possessing non-scaling qualities and considerable strength at high temperatures, and many others, to which reference is made in Chapter X.

From the practical standpoint the importance of alloy steels lies in the fact that they yield a greater range of mechanical properties than can be obtained in simple carbon steels, whilst they also yield either new physical properties or new combinations of properties. Whereas commercially pure iron (99·9 per cent. iron) has a tensile strength of 18 to 20 tons per sq. in., and a ductility corresponding to 40 per cent. extension in the test-piece, high tenacity alloy steels are available which have tensile strengths exceeding 100 tons, or even 200 tons when in the form of wire. One of the nickel-manganese alloy steels prepared by the author showed an extension of 76 per cent. on an 8-in. test-piece, with a tenacity of nearly 60 tons per sq. in.; whilst a specimen of manganese steel had a tenacity of 73 tons per sq. in., accompanied by no less than 78 per cent. of elongation. There is no other material extant which possesses these qualities to quite the same extent.

The wonders of modern engineering depend, more closely perhaps than is generally realised, upon the special qualities of the materials employed. It is important to remember that engineering science has progressed successfully just so far as the properties of the constructional materials available would permit. Improvements in materials have been followed immediately by advances in engineering practice—as witness the striking development which followed the introduction of manganese steel and silicon steel. On the other hand, the limitations of available materials impose from time to time a

check upon advance in other directions. Such indeed has been the chief difficulty in the way of the extended use of high pressure, high temperature steam-turbines, and the perfection of the internal combustion turbine; these developments have now been rendered possible by the discovery of steels which will withstand higher temperatures and higher stresses than the alloy steels hitherto known. Such products are now being very carefully studied, and, thanks to the work of M. Chevenard in France, great advances have resulted in this respect. The author is at present engaged, with his acquiescence and assistance and that of his company, in a number of investigations on these lines. There have already been produced remarkable steel alloy combinations which, even at the high temperature of 900° C., possess no less than 18 tons tenacity. These materials can also be heated in an oxidising flame to 1000° C., or even higher, and scarcely show any oxidation.

According to requirements it is possible, by the use of alloy steels, to reduce the weight of parts, whilst retaining or increasing their strength; to obtain strength combined with special ductility, hardness, or resistance to fatigue; and, in fact, to obtain or accentuate almost any desired physical property.

There still remain many fields in which further discoveries are required, so that the achievements of the past should encourage our younger men to fresh effort. The diversity of properties already obtained and demanded from alloy steels encourages us to hope for even greater variety in future; whilst, on the other hand, it emphasises the extreme importance of investigating as completely as possible every known and new material. Properties which are of little interest to-day may be in urgent demand to-morrow, and a great opportunity may lie before the worker who can meet the new requirements from his existing records.

Alloy Steels and Electrical Engineering.—As a metallurgist, it is not within the author's province to discuss at any great length the advances in electrical engineering, but it must be pointed out that these two important branches of science, metallurgy and electrical engineering, have rendered great assistance to each other.

Thus the names of Baily, Etchells, Frick, Girod, Greaves, Héroult, Kjellin, Moissan, Northrup, Ribaud, Siemens, Schneider, Stassano, and others who have helped on the application of

electricity to metallurgical processes should not be overlooked. On the other hand, metallurgists, both ferrous and non-ferrous, have rendered great service to the electrical engineer—in fact, many of the modern advances made in this branch of engineering would not have been possible without their aid.

This aspect of the subject has been fully dealt with in an article which the author was asked to contribute to the "Electrician"; this appeared in the issues dated November 28th and December 5th, 1924, under the heading of "Progress in Electrical Engineering."

As regards metallurgical products for electrical purposes, steel and iron castings and forgings are manufactured containing 99·80 to 99·90% of iron, and giving a permeability as high as, or higher than, expensive Swedish or charcoal iron. We have now also magnet steel containing cobalt possessing much greater retentivity and permanency as compared with the products formerly used.

Ferrous and non-ferrous materials possessing high resistivity, from 90 to 120 microhms per centimetre-cube, are produced in the form of wire strips and sheet.

Whilst at one time it seemed as if manganese steel might be employed for certain parts of electrical machines, these expectations have only been realised to a small extent. On the other hand, for the track work portions of electric tramways and electrically driven railways, its employment nowadays is an essential feature of construction and it is largely used in all countries.

The magnetic permeability of manganese steel is exceedingly low, practically unity, its electrical resistance is high, though it does not reach that of the nickel-manganese or nickel-chromium steel alloys. With regard to the present employment on a large scale of manganese steel for industrial purposes, this portion of the subject is dealt with fully in Chapter VII.

Amongst other steel products of value, either directly or indirectly, for electrical purposes, there is also silicon steel, invented by the author in 1884. This steel has helped to modify and improve the construction and working of electrical transformers and other electrical machinery and apparatus in a remarkable manner. It is dealt with more fully in Chapter VIII.

Alloy Steels and the Conservation of Iron.—Apart from their importance in providing mechanical and physical

properties otherwise unattainable, alloy steels are of enormous importance in relation to the conservation of iron. It was stated recently by the well-known geologist, Professor J. W. Gregory, F.R.S., that if the world's consumption of iron and steel went on increasing at the same rate as before the war, the supply of iron ores would probably be exhausted within 130 to 150 years. Such a prospect demands serious consideration, for we are, to some extent, stewards for the future; also an increasing scarcity of iron ores would lead to a serious rise in prices long before the shortage became acute.

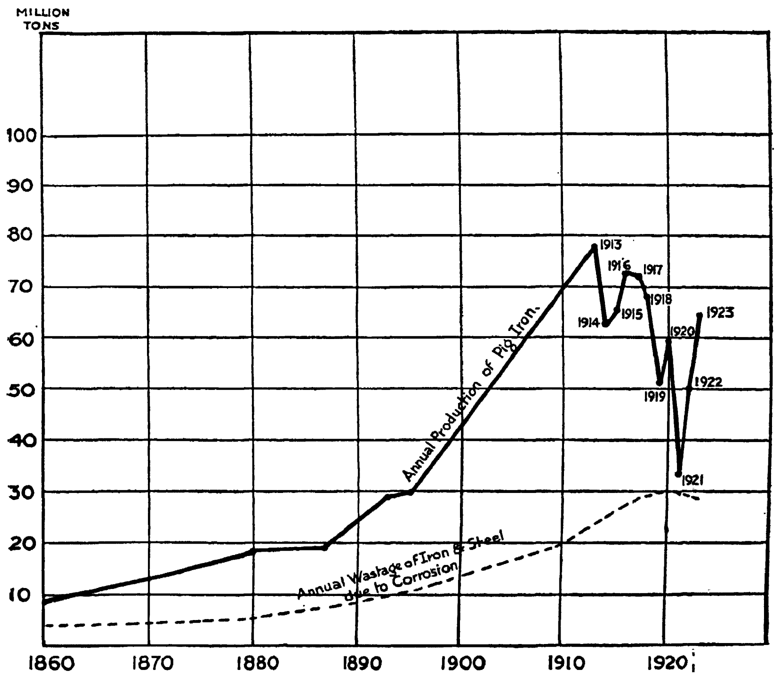


FIG. 2.—DIAGRAM SHOWING WORLD'S PRODUCTION OF PIG IRON FROM 1860 TO 1923, AND ANNUAL WASTAGE OF IRON AND STEEL RENDERED UNSERVICEABLE BY THE EFFECTS OF CORROSION.

Conservation of iron, both by reducing the quantity of iron used for a particular purpose and by reducing the wastage due to corrosion, is a problem of immediate economic importance; also it is one in the solution of which alloy steels will play a great and useful part: for example, 1 ton of manganese steel will do the work of about 10 tons of ordinary iron or steel,

owing to its remarkable durability in heavy service. Thus the use of alloy steels secures other advantages of even greater importance than the saving in the amount of iron used. For example, by the use of manganese steel the high cost of frequent renewals, and the time lost in making replacements, as well as the disorganisation of machinery which, meanwhile, is standing—all of which occur with ordinary steel—are entirely avoided or greatly reduced in frequency.

The accompanying chart (Fig. 2) shows the world's production of pig-iron from 1860 to 1923, also the annual wastage of iron and steel rendered unserviceable by the effects of corrosion. It will be seen that the amount of iron and steel thus going out of use in 1921 was nearly equal to the quantity of pig-iron estimated to have been produced in that year, and about 40 per cent. of the maximum annual production before

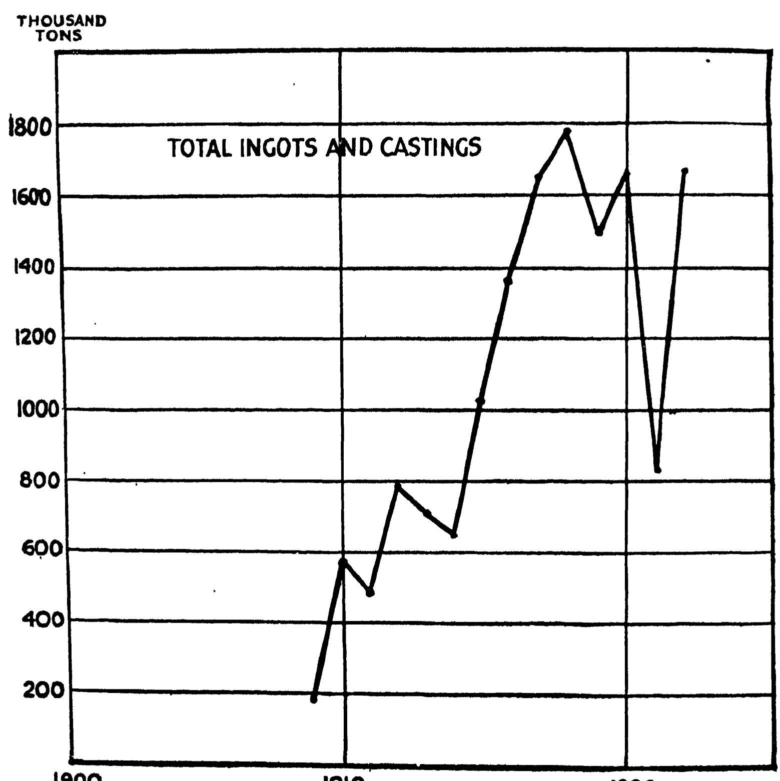


FIG. 3.—PRODUCTION OF ALLOY STEEL IN U.S.A.

the war. Here again, with our present-day knowledge of rust-resisting iron and steel, and with further knowledge which we may hope to acquire, the use of alloy steels should make possible important savings in the consumption of iron.

As shown in the accompanying Table V, and diagram, Fig. 3, in the United States alone, the weight of alloy steel products increased from 181,980 tons in 1909 to 1,787,852 tons in 1918, from which figures it is evident that the tonnage of special steels is amply sufficient to affect appreciably the conservation of iron.

TABLE V.—PRODUCTION OF ALLOY STEEL INGOTS AND CASTINGS IN THE UNITED STATES.

Years.	Ingots.	Castings.	Total.
1909	158,978	23,002	181,980
1910	538,462	29,357	567,819
1911	425,169	56,290	481,459
1912	689,392	103,109	792,501
1913	625,430	88,927	714,357
1914	577,107	69,846	646,953
1915	923,251	97,896	1,021,147
1916	1,306,157	56,458	1,362,615
1917	1,576,806	67,529	1,644,335
1918	1,721,367	66,485	1,787,852
1919	1,435,816	45,372	1,481,188
1920	1,591,939	68,353	1,660,292
1921	769,293	40,255	809,548
1922	1,614,392	59,104	1,673,496

Modernity of Alloy Steels.—Having shown, in Chapter IV, the antiquity of iron, it is but right that stress should now be laid upon the " modernity " of alloy steels. The enormous importance and large annual production of alloy steels, as exemplified in the preceding pages, is the more striking when it is remembered that alloy steels in the modern sense of the term, i.e., based upon scientific knowledge and procedure, are almost entirely the product of the last fifty years.

It has already been pointed out that during the three centuries—1550 to 1850—there was but little metallurgical literature of any real value, as we regard this to-day, or which could be considered likely to assist the remarkable progress which occurred later.

Even from 1860 to 1875 there were few important works on the metallurgy of iron and steel, except those of Dr. Percy, followed by those of Ede, Osborn, Fairbairn, Crookes, Röhrig, Grüner, Whitworth, Greenwood, Phillips, Barba, Ledebur, and Kohn's book on "Iron and Steel Manufacture," in the preparation of which the late Dr. Maw played an important part.

This position is not really to be wondered at, seeing that analytical chemistry, although greatly advanced in this later period, was still in a comparatively imperfect condition. Metallography was unknown. Mechanical and other special forms of testing, including hardness determinations, were in their infancy. Considering, therefore, the wonderful progress made during the last fifty years generally, and chiefly during the present century, it can be correctly said that there is no branch of science, except perhaps electrical engineering, which has advanced with such leaps and bounds as metallurgy has done.

Excepting the works mentioned as representing the knowledge prevailing some fifty years ago, it is clear that little thought had been devoted to or could be expected regarding the effects which various elements might produce when alloyed with iron. Still less had been achieved in the way of scientific investigation of the problem.

Whilst fully recognising the merits of those who have carried out researches of this nature in other countries, the honour can be claimed for great Britain of having in the main inaugurated the era of alloy steels. The leading metallurgists of other countries have all been most generous in stating that the author's discovery of manganese steel was practically the starting-point for most of our present-day knowledge concerning alloy steels and their technology. This point of view has been mentioned by such authorities as Stead, Roberts-Austen, White, Arnold, Barrett, Frémont, Howe, Sauveur, Pourcel, Gautier, Osmond, Dumas, Guillet, Mars, Benedicks, and many others.

In this connection a recent note by a well-known American metallurgist, Mr. Jerome Strauss, Chief of the Metallurgical and Testing Division of the American Navy Yard, Washington, D.C., may be quoted, not for any personal reason, but to support our national claims in this direction. Mr. Strauss stated his views in the following words :

"The history of modern alloy steel development begins with Hadfield's researches into the effect of large additions of ferro-manganese to soft steel. There had been previously some enquiry, of course, into the properties imparted by the introduction of manganese, nickel, chromium, and other elements, but these either were unsystematic or were discontinued (at least in the case of manganese) upon the first appearance of undesirable characteristics in the product, with the increasing percentages of the added element. Credit must, therefore, be given to Hadfield for his broader vision. His pioneering where others saw merely useless expenditure of effort opened a field which, in the forty years since the announcement of his success, has been widely settled, yet cultivated only in scattered spots. Our knowledge of alloy steels is still in its infancy. . . . Because of these and probably many unpublished failures, Hadfield's courage and success, and his discovery of the toughening treatment for the high manganese alloys, justify the recognition they have received."

The results of the researches which led to the discovery of manganese steel were recorded, in the early eighties, after which complete and full public presentation was made to the Institution of Civil Engineers in the session 1887–1888. The papers on "Manganese Steel" and "Some Newly Discovered Properties of Iron and Manganese," read and discussed in February, 1888, represented the first development of systematic researches regarding steel alloys. The alloy, manganese steel, with which they dealt, revolutionised metallurgical opinions as to alloys of iron, and it is somewhat remarkable that the discovery which inaugurated the era of special steels should have been virtually complete in itself. Except for the increased general experience in the manufacture of manganese steel, this material is practically of the same quality and type as when invented forty years ago. In other words, the systematic procedure which characterised the initial researches led to results which have needed no subsequent revision.

Since those days the author has published nearly 150 papers dealing with various alloy steels and other metallurgical advances a list of which is given in Appendix III. These represent an amount of work and an extent of progress in metallurgical science which, it is difficult to realise, has been accomplished in the comparatively short time of forty years. The facts disclosed by these particular researches remain as correct and as useful to-day as they were at the time of their discovery.

Early Attempts to make Alloy Steels.—Although the successful development of alloy steels has only been accomplished within the past half-century, several earlier attempts had been

made, and in justice to the workers of those days it is necessary to give at least a brief review of their activities.

Michael Faraday (Plate LX), best known by reason of those discoveries on which the whole of the electrical industry is based, undoubtedly foresaw that metallurgy was destined to become one of the principal branches of applied science, for, in addition to his other work, he devoted much time and energy to the study of alloys of iron with other elements, and in 1821 he published his work "Alloys of Steel" which, amongst other striking omissions, did not refer to any tests with tungsten. Some idea of the difficulties under which he worked may be gleaned from his statement (in 1822) that, as he could not go to Sheffield, he carefully prepared the mixtures in London, and sent them by coach under the care of an assistant who was to witness the desired processes at Sanderson's works.

It is not surprising that, under such conditions, Faraday did little to dispel the ignorance prevailing at that time concerning the alloys of iron, but it is interesting and encouraging to know that so eminent a scientist appreciated the importance of investigations in this field. In particular, he sought to obtain better cutting tools and non-corrodible metal for reflectors. Amongst others, he tried alloys of iron with gold, silver, and rhodium; he made an alloy containing 3 per cent. of nickel and found that it worked well; and he alloyed iron with chromium and might well have given us "rustless steel" nearly a century before it was actually marketed, had he continued this line of investigation!

By empirical methods based on the principle of "trial and error" the Mushets, father and son, to whom great credit should be given, evolved more than half a century ago a self-hardening alloy steel. This material was rather in the nature of superior cast-iron than steel. Its applications were severely limited—the alloy was relatively brittle and useful chiefly for tools—and its manufacture was for a long time shrouded in mystery.

At the time of the author's early experiments and, indeed, for many years thereafter, it was difficult or impossible to obtain—in commercial quantities and at a commercial price—supplies of ferro-alloys rich in the elements which it was desired to use in the preparation of alloy steels, and low in other elements, particularly carbon. Under such conditions it was impossible to prepare alloys with the ease and accuracy to which we are now accustomed, and much credit is due to the firm of Biermann

of Hanover, the Terre Noire Company, and a few other concerns for their activity in the earlier days of the manufacture of various special metals and special alloys.

Special reference should be made to the monumental work of M. Pourcel, of the Terre Noire Company, one of the Honorary Vice-Presidents of the Iron and Steel Institute. An account of his labours is to be found in the *Revue de Métallurgie* for April, 1924.

The credit for first appreciating the importance of ferro-alloys in the manufacture of steel appears to belong to M. P. Berthier who, in a report on alloys of chromium with iron and steel,* stated that he had spent much care on the preparation of ferro-chromium, not solely because he believed such material had in itself special value, but because he believed it would be found useful as a means of introducing chromium into cast steel. In the face of this statement it is surprising to find that this important point was first overlooked by Baur and others until their investigations led them to the same conclusion. Incidentally, it may be noted that M. Berthier acknowledged frankly in the same report that the idea of introducing chromium into steel was suggested to him by Faraday's interesting paper on "Alloying different Metals with Steel." This statement is important, because it has been alleged that Faraday obtained his idea from Berthier's work.

It is a noteworthy fact that Faraday and Berthier, two of the most brilliant men of their day, should have foreseen, more than a century ago, the ultimate importance of alloy steels. Had their work been adequately appreciated and developed at the time, the history of "special steels," as we now understand the term, might have begun much earlier, perhaps fifty years sooner than was actually the case. Then, as often since, the key to a discovery was found, but the portal was not opened wide.

Though tentative experiments were made by a number of earlier workers—amongst them Faraday, Berthier, Frémy, Percy, David and Robert Mushet, A. Parks, and H. Biermann—the author's investigations lead to the conclusion that Julius Baur, of New York, was the first to introduce on a practical scale the manufacture of chromium steel. His first patent on this subject was taken out in 1865, and was followed in 1869 by

* *Annales de Chimie*, 1821, vol. xvii.

various improvements. It was not until about 1876 that Baur definitely adopted ferro-chromium in preference to chrome ore as a means of producing regular and reliable alloys. As already pointed out, the value of ferro-chromium in this connection had been realised by Berthier many years before. In 1875 Brustlein, of the Holtzer firm, commenced in France his experiments on chromium steel. This led to his firm supplying such steel for industrial purposes in 1877. In the author's opinion it was largely owing to Brustlein's work that the great development of chromium steel has been made possible. His keen, active interest, as evidenced in wide and lengthy correspondence between himself and the author for many years, showed the high value of the many suggestions and practical results which proceeded from his activities in advancing the science of metallurgy.

Ferro-Manganese.—From the records available it appears that the value of manganese in steel-making was appreciated, at least by some workers, nearly forty years before a cheap and reliable "ferro-manganese" could be obtained as a convenient means of introducing manganese into the steel.

Heath, about 1840, was probably the first to recognise fully the utility of manganese in the manufacture of steel, and he applied the black oxide to the manufacture of crucible cast steel. Robert Mushet used manganese alloys on a much wider scale to cheapen the manufacture of crucible and Bessemer steel.

Kohn states in his excellent book on "Iron and Steel Manufacture" that, in 1868, works for the production of iron and manganese alloys were erected by Mr. Henderson, at Glasgow, who was reported to make a very pure alloy of iron and manganese containing from 25 to 30 per cent. of the latter metal, with of course a high percentage of carbon, and possessing many advantages over spiegeleisen, which it was thought would be replaced. It was, however, not until about ten years later that the Terre Noire Company in France, made available by the cheaper blast furnace practice, certain combinations or raw alloys, known as ferro-manganese, containing up to 80 per cent. of manganese. These were, however, high in carbon content, 6 to 8 per cent., and not malleable—in fact, they were of the nature of cast-iron. These products made possible the wholesale manufacture of excellent soft steels, and, as the use of "high" ferro-manganese, containing up to 80 per cent. of manganese, is essential to the commercial manufacture of manganese steel,

the Terre Noir Company rendered a doubly valuable service to metallurgy by improving and cheapening the supplies of "ferro."

The exhibits shown by the Terre Noire Company at Paris in 1878 were accompanied by an instructive pamphlet showing the influence, as then practised, of different bodies alloyed with iron and suggesting further investigations. Amongst these were the experiments with varying percentages of manganese, up to 2·5 per cent., but no higher percentage was mentioned. At this point, owing to the brittleness of the product, whether cast or forged, the series was stopped, for it was assumed—erroneously, as events proved—that further additions of manganese would only produce still more harmful effects.

The Dawn of a New Era.—The author, who was then (1878) only about twenty years of age, translated the whole of the Terre Noire Company's pamphlet, some forty pages in all, containing as it did very complete tables of tests, composition, heat-treatment, and other information. It was probably due to the impression made on his mind by this pamphlet that he was inspired by the results—both positive and negative—obtained by the Terre Noire Company, to carry on the important series of alloys of iron and other elements which then followed at his hands and finally resulted in the important invention of manganese steel.

The author carried out systematic investigations with alloys containing higher percentages of manganese and thus discovered that, when the amount of this element exceeded 6½ or 7 per cent., the physical properties of the alloy underwent remarkable changes. The strength and ductility increased, the metal became non-magnetic, and there were other changes, all indicating the formation of an entirely new material.

Manganese steel was the first malleable, non-magnetic ferrous product to be discovered and, though its other properties have proved to be of greater practical importance, its non-magnetic character has rightly attracted much interest and speculation, whether at the hands of the scientific investigator or those more directly engaged in the practical application of such qualities. Even to-day there is much to be learnt concerning the manner in which 13 per cent. or so of manganese is capable of suppressing the magnetic properties of 87 per cent. of iron.

This alloy, which is described more fully in Chapter VII, has so many remarkable and useful properties—some of them diametrically opposed to those of any other steels—that, in the

words of that eminent metallurgist, the late Dr. J. E. Stead, F.R.S., it "has surprised the whole metallurgical world with the results obtained. The material produced is one of the most marvellous ever brought before the public."

Concerning the invention and discovery of manganese steel, which included not only the composition but also the heat treatment and toughening, there is the following entry in the author's experimental records book under the date of September 7th, 1882: "I was led to make the following experiments with a view to the production of a very hard steel for tramway wheels, and grinding wheels or discs to be used in the place of emery wheels. *The experiments have led to some very curious, perhaps most momentous, results that may to some extent entirely revolutionise metallurgical opinions as regards alloys of iron and steel.*" The concluding sentence of this excerpt is here italicised in order to call special attention to a prediction which was rather bold for a youth twenty-two years of age, but which proved to be quite correct as subsequent events have shown.

The statements of many of the world's leading metallurgists, some of whom are quoted below for the purpose of collected record, show that the discovery of manganese steel, which could either be cast into form or forged into shape, laid open the field of "alloy steels," as the term is now understood, and led the way to entirely new ideas regarding combinations of iron with other elements.

On September 14th, 1884, Monsieur Gautier, of the Terre Noire Company, who themselves had at that time paid a certain amount of attention to the study of alloys, wrote to the author as follows: "I thank you very much for your beautiful sample of manganese steel. After carefully examining and inspecting the fracture and the other tests, I feel bound to state that this manganese steel is an entirely new kind of steel and is a new invention. Such steel has never previously been manufactured. In fact, this manganese steel could not now or previously have been made except for the introduction by myself and others of high percentages of ferro-manganese containing 60 to 84 % of metallic manganese. These high percentages of ferro-manganese have been and could only be made during the last few years." As mentioned elsewhere, this statement was quite correct.

In view of the fact that the cheap production of rich ferro-manganese is essential to modern metallurgy, the world owes a

deep debt of gratitude to the guiding spirits and great experimentalists of the Terre Noire Company, Messieurs Euverte, Pourcel, and Gautier. As a matter of considerable interest, it is well worth putting on record the valuable work these pioneers accomplished in their early alloy steel researches, be it remembered, as far back as 1878. They made, and presented at the Paris Exhibition of that year, what was then considered a complete series of varying carbon steels, namely, ·15, ·49, ·70, ·87, 1·05 % C, with about ·02 to ·04 S, ·03 to ·06 P, ·20 to ·26 Mn % ; one specimen of chromium steel ; also a series of phosphorous steels containing ·24, ·27, ·39 % of that element, with ·30 C and ·75 Mn %. As regards manganese-iron alloys, they made a series of five specimens containing carbon from ·45 to ·59 %, about ·03 to ·069 % each S and P ; the manganese varied as follows, ·52, 1·06, 1·30, 2·00, 2·45 %. Their researches were accompanied by mechanical tests, including tensile, compression, and drop tup tests. These investigators found that on adding 2·45 % Mn a brittle and comparatively useless product was obtained, so they did not pursue their experiments in the direction followed by the author, which resulted in the discovery of manganese steel.

In the same way, the author's old friend, the late Monsieur H. Brustlein of Messrs. Jacob Holtzer, Unieux, France, who did so much to help on the development of alloys of iron and chromium, also admitted that whilst he had experimented on alloys of iron and manganese, he had not exceeded about 7 % of manganese.

The late Sir William Roberts-Austen, F.R.S., formerly President of the Iron and Steel Institute, mentioned in 1888 that the iron-manganese alloys then described before the Institution of Civil Engineers represented a most remarkable series of materials and that he thought their discoverer was entitled to the gratitude of all metallurgists and engineers. In the same year Monsieur A. Pourcel, the well-known French metallurgist, stated that he considered the production of manganese steel the most important event in practical metallurgy during the preceding ten years, and one which took its place beside the result of the labours of Bessemer, Mushet, Martin, Siemens, and Gilchrist.

The late Professor F. Osmond, the leading metallurgist in France of the last thirty years, said in 1888 that the discovery and invention of manganese steel was not only the discovery of a new alloy, curious, of great scientific value and yet useful, but in the history of the metallurgy of iron it ranked as a

discovery equal in importance to that of the effect of quenching carbon steel, and was the only one of the same order which it had been reserved for our age to make.

More recently, an eminent American metallurgist, the late Professor H. M. Howe, said in 1903 that this steel had a combination of properties which, as far as he knew, was not possessed by any other known substance when this remarkable alloy was discovered. Professor B. Stoughton, also a well-known American metallurgist, said in 1911 that the story of the discovery of manganese steel would be an inspiration to every inventor; and another American metallurgist of high standing, Professor A. Sauveur, of Harvard, the recipient of the Bessemer Gold Medal in 1924, has said that what might be termed the alloy steel era was practically ushered in by the discovery of manganese steel in 1882.

This research was further recognised in 1921, by the Engineering Foundation, which represents the whole of the various engineering and similar societies in the United States, by the award the John Fritz Gold Medal for, to quote their terms of reference, the "invention of manganese steel."

Quite apart from the author's personal connection with them, these statements are useful for historical reference, and it is hoped that they may be a stimulation to the rising generation of metallurgists in exploring new fields.

Historic Experiments.—In the light of present day knowledge it is specially interesting to trace the birth of a discovery and, for this reason, there is given below an extract from the notes relating to the discovery of manganese steel; whilst, in Chapter VIII, there are given corresponding extracts concerning the invention of silicon steel.

The following is an account, taken exactly from the author's record book of the research commenced on September 7th, 1882, when he made the experimental steel now described, and estimated approximately to have the following composition: Carbon 1·50; silicon 3·96; manganese 7·45; and iron about 87·00%. The mixture was made up as follows:

9 lbs. of 82 per cent. to 84 per cent. ferro-manganese.
49 lbs. of W.D. 8 per cent. silicon pig-iron.
41 lbs. of decarbonised iron.

———

99 lbs.

From this mixture the author cast one emery wheel disc, two tools, and two nail cutters as used in Staffordshire, one $4\frac{1}{2}$ inches and the other $7\frac{1}{4}$ inches in diameter. These seemed very hard when grinding off the fashes; both were sent for testing to the firm of Eliza Tinsley, the famous nail-makers of Staffordshire. The large cutter weighed slightly less than one of ordinary steel melted in the crucible, and gave a much sharper note when struck with a hammer—a beautifully clear note. The emery wheel disc was duly mounted and tested, but did not give the expected cutting or grinding action, it only "glazed." The casting itself was very smooth, 12 inches in diameter and 2 inches in thickness, cast with a slight recess for the face plate and a core in the centre $1\frac{1}{2}$ inches diameter to take the spindle.

It will be noted that reference is made to the casting of an emery wheel disc. Singular to say, it was the making of this particular article which led to the discovery of both manganese steel and silicon steel, an account of which is given more fully in Chapter VIII, relating to silicon steel.

The steel "settled" well, showing plenty of flux or slag, but was found to be so hard that when chipping off the runner the material spoilt half a dozen chisels and sets. This disc casting was tested with a file by "David," the head foreman of the Machine Shop in the Engineering Department at the Hecla Works in Sheffield, and he reported that the casting was even harder than chilled metal.

Two tools were also made from a portion of scrap, melted in the crucible. One of the tools cut off a steel casting runner, 6 inches in diameter; the edge was perfect, but broke when tried on the next casting. The material would not forge, crumbling at a very low heat.

This steel was evidently excessively hard, but at the expense of toughness. It was thought that the excess of silicon present must be the cause of this, and in the next experiment, which took place shortly afterwards, two ingots were made, but this time no silicon was added in any form. Now come the strange and peculiar results.

Ingot No. 1 was made as follows: $8\frac{1}{2}$ lbs. of ferro-manganese, containing about 80% of manganese, were added to $47\frac{1}{2}$ lbs. of fluid steel, poured from a larger ladle containing molten metal as used for steel castings, giving a total weight of 56 lbs.

The actual analysis of the final alloy steel showed the following composition: carbon 1·35%; silicon 0·69%;

manganese 12·76%. From this steel there were cast one ingot and two cast turning tools. A sample of the ingot was sent to Woolwich Arsenal for making various special tests.

Ingot No. 2 was made from 5 lbs. of 82 to 84% ferro-manganese added to 53 lbs. of ordinary casting steel as above, giving the total weight of 58 lbs.

The remarks in the notebook about this steel, No. 2, were to the effect that it seemed tough but rather softer than No. 1. The composition was: carbon 0·70%; silicon 0·69%; manganese 7·58%. As regards the steel from No. 1 ingot containing 12·76% manganese this proved to be a very tough material, possessing a most peculiar fracture, with crystals which, owing to their length, might almost be termed *fibres*. To all appearances the steel looked very soft, and the author expected it would be of no use. So thought William Percival, the head foreman of the Steel Department. But, on using a file, lo and behold the steel seemed to take the serrations off the file almost as an emery wheel would have done! Notwithstanding this the steel was exceedingly tough, and it was found very difficult to "top" the ingot, that is, to break off the upper portion. There had thus been discovered a steel which, under certain conditions, was not only extraordinarily hard but also very tough, two apparently opposite qualities combined in one material.

One of the firm's experienced fitters, "Dick Smith," also "David," both filed the steel and pronounced it to be exceedingly hard. The author tried a lathe "nosing" tool of the steel, which at first cut well, then lost its edge, but did not show any snipping.

The results on the whole were not, however, bad for a cast product, and as regards the tool-test mentioned it was thought at first that the heat from the friction in cutting had made it lose its temper.

The author then heated the steel to a high temperature, about a low yellow colour, and quenched it in water, expecting of course that it would harden like high carbon steel. Strange to say, if anything, the material had now become slightly softer and much tougher than before. This experiment was the discovery that manganese steel on being quenched in cold water from high temperatures, 900 to 1,100° C., did not harden but became tough—in fact, exceedingly tough.

Amongst other characteristics of this steel, the author also

discovered its peculiar non-magnetic qualities, in spite of the presence of 88·00 to 90·00% of the metal iron; also its low conductivity. Manganese steel is an extraordinarily bad conductor of either heat or electricity, and being impressed at the time by its low thermal conductivity the author made for his fire-place a manganese steel poker, the handle of which did not become too hot, even when the poker was left in the fire all day, whereas one made of ordinary steel soon became so hot that it could not be handled.

Thus is described from the original notes in the experimental book the discovery of manganese steel, from which sprang later such further important discoveries in alloy steel by the author and a host of other investigators.

It is impossible here to describe the many hundreds of important experiments subsequently performed. It may be interesting, however, to mention specially how it was found that when reducing the amount of manganese to about 4%, or about one-third of the amount present in "Manganese Steel," by which means it was expected to get a steel of stronger and better nature than with 12%, the altogether unexpected happened. The steel containing the lower percentage of manganese, that is 4%, instead of being tougher, was so hard and brittle that castings made of it, when dropped on the ground broke into many fragments. Thus it was found that this steel did not even possess the strength of cast-iron. Yet, at the same time, it was exceedingly malleable when heated and hammered, though remaining proportionately as brittle in the forged as in the cast state. Its tenacity was not more than about 30 tons per square inch, with practically no elongation. Heating this material to either low or high temperatures and quenching in water made little or no difference; it remained unserviceable and of apparently no practical value.

The author thus established a new law, at any rate as regards ferrous compounds, namely, that whilst up to about 1%, and in some cases 1·5%, of manganese was most useful for the production of ordinary steel, as soon as the amount reached the region of about 3% and up to 7%, the steel was so brittle as to be of little or no value, either in the cast or forged conditions. Upon further increasing the percentage of manganese to between 10 and 15%, especially after heating to a high temperature and quenching in water, the manganese steel produced was wonderfully tough, the tenacity being 60 to 70 tons per square inch,

the elongations varying from 50 to 70%. An amount higher than 15% produced still another type of steel. This, however, being more expensive and not offering any special features of advantage, was not found of any particular industrial value.

It has, therefore, been well said by so many metallurgical authorities that the results were not only most extraordinary, but that a new material had appeared in the world's metallurgical productions, and one which pointed out the way and helped to bring about the many other important developments which naturally followed.

An exhibit of various manganese steel specimens took place at the Institution of Mechanical Engineers in January, 1884, by the author's father, Mr. Robert Hadfield. This was the first public exhibition of manganese steel, reference being made to it in the Proceedings of the Institution and in articles written on the subject which appeared in *The Engineer* on February 1st and 8th, 1884.

Assistance Received from Others.—In Appendix IV of this book there is presented a special table of some two hundred and sixty-five names, including metallurgists, engineers, electrical engineers, chemists, physicists, and others with whom the author has come in contact during his work in the field of metallurgy. Although he has often freely expressed his obligations to these various friends—alas, many of them passed away—he gladly does so once more, for without their advice, and in some cases assistance, specially in the early days, it would not have been possible to have obtained the many results presented from time to time.

When first investigating the field of iron alloys, then a new and virgin field, the author was specially fortunate in being able to supplement his own knowledge as a metallurgist with scientific training, by the advice, encouragement, and help of others in different branches of science. Further mention is made later (Chapter XV) of the names tabulated in Appendix IV, but it is specially appropriate to refer here in greater detail to some of those who helped in one way or another with the development of the author's alloy steels. In most cases the reference here is to valuable work performed many years ago. Wherever possible, later assistance is acknowledged elsewhere in this volume, but there are many others, including those on the Continent and in America, to whom the author would have liked to make reference had space permitted.

Amongst the well-known scientific and technical men in this country, on the Continent, and in America, who were concerned and interested in the earlier examinations of manganese steel, and whose names the author has pleasure in placing on record in this connection, may be mentioned: Kelvin, Anderson, Armstrong, Arnold, Akermann, Barnaby, Barrett, Beaumont, Benedicks, Bottomley, Crompton, Dumas, Ewing, Fleming, Frémont, Gautier, Gilchrist, Greenwood, Goodman, Hall, J. Hopkinson, B. Hopkinson, Hibbard, Howe, Kennedy, H. and A. Le Chatelier, Ledebur, Mordey, Onnes, Osmond, Pourcel, Ramsay, Reinold, Roberts-Austen, Edward Riley, Sauveur, Schneider, Sorby, Stoughton, Stead, Taylor, Thwaite, Unwin, Wedding, Weeks, and Young.

Lord Kelvin.—The achievements of Lord Kelvin, whose portrait is shown in Plate XIII, are known throughout the world and it is impossible to overestimate the value of the many services he rendered to the cause of science. The author will ever remember the many acts of kindness and consideration shown to him by Lord Kelvin from time to time.

James T. Bottomley.—In the *Electrical Engineer* of October, 1885, it was announced: "A specimen of manganese steel made under the Hadfield patents was presented to Sir William Thompson (afterwards Lord Kelvin) by Mr. R. R. Eadon, of Messrs. Moses Eadon & Sons, Sheffield." This specimen may have been handed to Dr. Bottomley by Lord Kelvin. However, be that as it may, there is no doubt that the first electrical determination on this material was made by Dr. J. T. Bottomley, M.A., F.R.S., whose portrait is shown on Plate XIII, and the results obtained were announced at the British Association Meeting at Aberdeen, 1885, in his paper on "A Specimen of Almost Unmagnetisable Steel."

Dr. Bottomley's kindly assistance at that time, and later on, was a great encouragement; he was the earliest scientific worker with whom the author came in contact concerning manganese steel, and he obtained from the author many specimens of this material for scientific investigation.

John Hopkinson.—The late Dr. John Hopkinson, F.R.S., whose name was a household word in the early days of electrical developments, and whose portrait is shown in Plate XIII, carried out a large number of magnetic experiments, some of them being on the many specimens of alloy steels furnished by the author. His experiments and tests were described in a number

of important papers to the Royal Society, the Institution of Electrical Engineers, and other bodies, the chief ones on this subject being delivered in the years 1885 to 1895. His various contributions are embodied in two volumes edited by his son, the late Professor Bertram Hopkinson, and entitled "Original Papers by the late John Hopkinson, D.Sc., F.R.S."

It was he who introduced the term "coercive force" in his paper "Magnetisation of Iron," read before the Royal Society in 1885, and in the same paper his early experiments are described, including references to tests, amongst others, on specimens of the Hadfield manganese steel containing 12% manganese; manganese-iron alloys containing 4·7 and 8·7% manganese; silicon steel; chromium steel; and tungsten steel. In the same series were included important tests upon wrought iron, malleable cast-iron, grey cast-iron, Bessemer mild steel, Whitworth mild steel, mild cast-iron, white cast-iron, and spiegeleisen. All these were of great interest, and special reference is made to some of them later in this book.

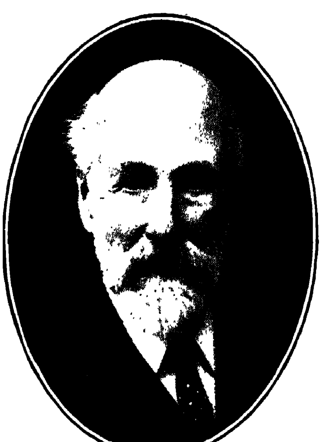
Somewhat full particulars are given of Hopkinson's experiments on silicon steel, because they bring out the remarkable differences between silicon steel containing 0·20% carbon and under, as compared with 0·68% carbon in the specimen with which he experimented. The silicon steel with the higher carbon was useless for transformer sheets, but, as will be seen from data quoted later, its electrical resistance was equal to that of silicon steel with the lower carbon as now used. Thus, the high resistance noticed, about 50 to 60 microhms per centimetre-cube, appears to be largely independent of the carbon percentage.

Sir William Barrett.—The author has pleasure in giving on Plate XIII a portrait of the late Sir William Barrett, F.R.S., one of the hundred distinguished men who founded the Physical Society of London, which recently celebrated its jubilee.

The same specimen of manganese steel, which Dr. Bottomley had examined, was afterwards handed to Professor Barrett, who presented an interesting paper on "The Physical Properties of Manganese Steel" to the Royal Dublin Society; this was read on December 5th, 1886, and the non-magnetic qualities of the alloy were fully described. Further papers were read by the same author at the British Association Meeting held at Manchester, September, 1887; also "On the Magnetic Moment

LORD KELVIN, F.R.S.
1824-1907.

DR. J. T. BOTTOMLEY, F.R.S.



SIR WILLIAM BARRETT, F.R.S.
1844-1925.

PROFESSOR J. HOPKINSON, F.R.S.
1849-1898.

and other Physical Constants of Steel containing from 1% to 21% of Manganese," November 20th, and December 18th, 1889, before the Royal Dublin Society.

Mention is made elsewhere in this book concerning Sir William's experiments upon the author's silicon and other steels, also in Chapter IX reference is made to his important discovery of the phenomenon of recalescence.

Sir J. Alfred Ewing.—Professor, now Sir J. A. Ewing, F.R.S., whose portrait is given in Plate XIV, should be specially mentioned, as it was he who made such an exhaustive study of the magnetic quality known as "hysteresis," later discussed in connection with silicon steel—in fact, he introduced this important term as applied to metallic alloys. He first described this in the paper he read in 1881 before the Royal Society.

Professor Ewing, then at University College, Dundee, and Mr. William Low, also read a paper "On the Magnetisation of Hadfield's Manganese Steel in Strong Fields" in September, 1887.

In his remarkable book on "Magnetic Induction of Iron and Other Materials," which was published in 1892, and has since run through several editions, Ewing speaks of magnetic hysteresis as being the persistence of the metal in any magnetic state which it may have acquired, and he terms this as "lag." He also describes this quality as the residual effects exhibited by various qualities of iron and steel, the hysteresis observed being the tendency of the effects to lag, in phase, behind the cause that produces them.

He regards hysteresis as a species of magnetic fatigue which wastes energy at every reversal of the magnetism, and occurs in all kinds of iron, but particularly in all hard kinds of iron and steel. To minimise this source of loss, the cores of armatures and transformers must be made of material which has as low a hysteresis as possible.

Ewing's classic work is of high order, and is still of great service to those studying the particular phases of electrical phenomena with which he dealt, including the qualities of permeability, resistance, coercive force, hysteresis, and eddy current losses.

W. Brown.—Professor W. Brown, formerly Professor of Applied Physics in the Royal College of Science, Ireland, took an important part in the investigations, the results of which appeared in the three papers presented to the Royal

Dublin Society in 1899, 1902, and 1904, by Barrett, Brown, and Hadfield. These papers described important researches into the electrical and magnetic properties of the many Hadfield alloy steels.

Professor Brown was a former pupil of Lord Kelvin, and every credit should be given to him for his share in this valuable early work of experimental nature.

In addition to his work at the Royal College of Science, Dublin, both as assistant physicist to Sir William Barrett, and afterwards when he succeeded to the Chair of Applied Physics there, Professor Brown contributed many other papers, including that read by him before the Royal Dublin Society in 1907 on " The Densities and Specific Heats of Some Alloys of Iron." The research formed one of the series carried out to investigate the several physical qualities of the author's various alloy steels. The paper describing the results dealt with over one hundred specimens of iron and its alloys, all of which were supplied by the author, many of them being made before 1890. Their compositions, the foundation of a research of this kind, were originated by the author, and their production and manufacture were also carried out directly under his supervision, as well as all the chemical and mechanical tests. They certainly comprised a complete and unique series of alloys of iron with carbon, manganese, nickel, tungsten, silicon, chromium, copper, cobalt, aluminium, and other elements.

Professor Brown also contributed to the same Society two papers on " Permanent Steel Magnets " and " Chromium Steel Permanent Magnets " in 1910 ; the author was happy to supply most of the specimens for the first of these papers and all of those for the second, which dealt with researches upon chromium steel bars of various percentages between 1·75 and 9·22% Cr.

Professor Brown is also joint-author of three books on physical and electrical subjects.

Sir William H. Preece.—The late Sir William H. Preece, K.C.B., F.R.S., of whom a portrait is shown in Plate XIV, was throughout his long life of eighty years an indefatigable worker in the field of electrical engineering. His contributions of scientific papers were numerous and valuable, and his year of office as President of the Institution of Civil Engineers was a markedly successful one.

As stated by Dr. Benedicks, in his " Physical and Physico-Chemical Researches on Carbon Steel," it was Preece who

determined in 1887 the exact resistance of pure iron, obtaining the figure of 9·733 microhms as against that of 10·769 previously accepted. This determination is a most important scientific basis point as regards all experimental work relating to the metal iron and its alloys.

It was Sir William Preece who described Senator Marconi's first experiment with directed waves, in September, 1896, at the Meeting of the British Association for the Advancement of Science, and in a Lecture delivered by him at the Royal Institution in London, in June, 1897.

As "Nature" in 1913 rightly said in his obituary notice, "Genial, cheery, thorough, and industrious to the last degree, Sir William Preece's name and memory will long be cherished." The author will never forget and cannot speak too highly of Sir William's many acts of personal kindness and of his interest in the author's various research work.

J. A. Fleming.—Another eminent scientist with whom the author corresponded and collaborated on electrical matters, including the joint-paper read by us before the Royal Society in 1905, on "The Magnetic Qualities of some Alloys not containing Iron," was Professor J. A. Fleming, F.R.S., shown in Plate XIV, whose name is now a household word. His kindly encouragement in the earlier days of the author's metallurgical researches was of the utmost value and assistance.

His great work in connection with the applications of electrical science over the last thirty years is widely known throughout the world. His invention of the thermionic valve has revolutionised wireless telegraphy, and also made wireless telephony possible.

In the lecture by him on "The Ferro-magnetic Properties of Iron and Steel," which at the author's suggestion he was kind enough to give before the Sheffield Society of Engineers and Metallurgists on October 18th, 1897, most valuable information was presented; much of it of service, even to-day.

He pointed out that the phenomenon of the retentivity is not dependent upon the presence of carbon in the alloy, and that it exists, even in chemically pure iron or nickel. Coercivity is, however, very much affected by the chemical composition of the material.

He also stated that the ferro-magnetic quality of iron or steel, given in the form of a ring, is completely determined when we know at each degree of temperature, and for various

flux-densities, during a cycle, (1) the permeability, (2) the retentivity, (3) the coercivity, (4) the hysteretic constant. The effect of temperature on the hysteretic constant of iron is very marked.

If iron is continuously heated up, the hysteretic constant diminishes as the temperature rises, and it was shown by Dr. G. K. Morris that it vanishes entirely at about 800° C. or at the critical temperature. It had also been discovered some time previously by Mr. W. Mordey that prolonged slow heating of iron to only 60° C. or 90° C. had a marked effect on the hysteretic constant, and the result is often to increase this constant two or three times. The effect varies with the annealing of the iron, and in many cases the iron, which shows the least hysteretic constant at starting, experiences the largest percentage increase of it on prolonged heating. This effect is called the magnetic ageing of the iron. Owing to the large use of iron for transformer purposes ageing was, at that time, a very serious difficulty met with in the working of transformers. By the use of silicon steel most of this difficulty has been removed.

Fleming, in the lecture above mentioned, drew a comparison between the physical properties of iron at 1,000° C. and at 100° C., showing that they represent two totally different substances. His conclusions were summarised as follows: —

In the case of iron at 100° *C.*:—	*In the case of iron at* 1,000° *C.*:—
The magnetic permeability may be as much as 4,000 C.G.S. units.	The magnetic permeability is about unity.
The specific heat is about 0·108.	The specific heat is about 0·218.
The electrical resistivity is about 16,000 C.G.S. units, or, say, 16 microhms per centimetre-cube.	The electrical resistivity is 120,000 C.G.S. units, or, say, 120 microhms per centimetre-cube.
The temperature coefficient is 0·5 per cent. per degree.	The temperature coefficient is 0·02 per cent. per degree.
The magnetic susceptibility varies greatly with the flux-density or induction.	What little susceptibility remains is independent of the flux-density or induction.
The flux changes involve a magnetic hysteresis.	The flux changes involve no hysteresis.
The iron is a ferro-magnetic body.	Iron is merely a para-magnetic body.

"All these physical changes take place at the critical temperature, and if identity of physical properties constitutes identity of substance, we are entitled to say that iron at 1000° C. is not the same substance as iron at 100° C. This, I think, argues some breaking-up of the molecule of the kind I have indicated, or some change of an equivalent nature"

SIR WILLIAM PREECE, F.R.S.
1834-1913.

DR. J. A. FLEMING, F.R.S.

SIR ALFRED EWING, F.R.S.

MR. W. M. MORDEY, M.I.E.E.

PROFESSOR B. HOPKINSON, F.R.S.
1874-1918.

Fleming, later on in this lecture, stated—

> "The addition of bonding elements like carbon to iron will always then increase its resistivity, decrease its temperature coefficient, decrease its magnetic permeability, increase its hysteretic constant, and also increase within limits, if it is combined carbon, its rigidity and tensile strength. I think there is some indirect evidence, therefore, that in a solid metal like iron we have to deal with two classes of molecules, some more free and independent, and some less free and independent, and this theory fits in with many facts; and it offers a suggestion as to the reason bonding elements, like polyvalent atoms of carbon, sulphur, manganese, phosphorus and silicon, have even in small proportions such a marked effect upon the magnetic, electric, and mechanical qualities of iron."

The author has quoted somewhat fully from this early paper because it is probably one of the clearest expositions which has been presented on the subject of what magnetism is in its relation to iron and its alloys.

W. M. Mordey.—Mr. W. M. Mordey, M.Inst.C.E., whose portrait is shown in Plate XIV, was President of the Institution of Electrical Engineers in 1908-9. He has been actively engaged in electrical engineering at home and abroad for over forty years, and is at present a member of the London University Board of Advisors of the Board of Studies in Electrical Engineering, also a member of the Governing Body of the Imperial College of Science and Technology. He was awarded a Gold Medal by the Institution of Civil Engineers, and has communicated numerous papers to the Royal Society, the British Association, the Institution of Electrical Engineers, and the Institution of Civil Engineers. Many important electrical problems have received considerable assistance from the study which he has given to them.

In addition to much valuable work in the field of heavy and industrial electrical engineering, Mr. W. M. Mordey has made many experiments in connection with some novel and unlooked-for effects of alternating magnetic fields upon finely divided magnetic materials. This subject he brought, not long ago, before the Royal Institution in the form of a most interesting lecture.

Great credit is due to Mr. Mordey for his far-seeing views on many electrical developments, including the special attention he has paid to the study of the subject of effecting saving in the serious losses which occur in magnetising iron.

He undertook a very thorough investigation into the nature

of the phenomenon of magnetic ageing or hysteresis growth, and as the result was able to determine its true cause. This research is recorded in his paper " On Slow Changes in the Magnetic Permeability of Iron," read before the Royal Society on January 17th, 1895. His conclusions were that magnetic ageing is a physical change resulting from long-continued heating at a very moderate temperature, and it appears to be greater if pressure is applied during heating; it is not produced when the iron is not allowed to rise more than a few degrees above the ordinary atmosphere. The effect is not, as had previously been supposed by many, fatigue of the iron caused directly by repeated magnetic reversals, and neither magnetic nor electric action is necessary to its production. He also found that iron so aged does not return to its original condition if kept unused and at ordinary atmospheric temperatures, whether the periods of rest are short or long. It can, however, be restored to its original condition by reannealing.

A further valuable paper was read by Mr. Mordey and Mr. A. G. Hansard, at the British Association Meeting at Cambridge in 1904, on the subject of " Energy Losses in Magnetising Iron." Being present at this meeting, the author of this book was asked to open the discussion on the paper, and in his remarks mentioned that for some years he had been making experiments with special alloy steels, with the hope of arriving at results which the electrical engineer could utilise. He also pointed out how difficult these special alloys were to prepare and treat, but that, thanks to the help given by the scientist in improving our means of accurately determining composition, temperatures and treatment methods, there was hope that a great improvement in the materials used by the electrical engineer would be brought about in due course, and so it has proved to be.

To show further the importance of this development and the difficulties surrounding the problem, it may be mentioned that in the paper in question Mr. Mordey stated that " until some iron or steel has been discovered having a higher specific resistance combined with high magnetic qualities, the only way to reduce the difficulties, that is, due to current losses, is to use as thin iron as possible." This is an indication of the difficulties with which the electrical engineer was then contending. Mr. Mordey's all-round knowledge of this problem proved to be most useful. Before, therefore, concluding this brief description of some of Mr. Mordey's varied work, the author

would like to take the opportunity of saying that he rendered most valuable help by his advice during the early development of silicon steel.

Bertram Hopkinson.—Professor Bertram Hopkinson, F.R.S., a portrait of whom is shown in Plate XIV, the son of Dr. John Hopkinson, was one of the author's closest friends in the scientific world. He collaborated in several papers which at the time aroused the most interesting discussions, and proved to be of much service. His untimely loss, whilst carrying out his many services to our country during the war, at such an early stage in his career, was indeed a calamity. Without doubt, whether as regards his work as a physicist, or on engineering and allied subjects, or his educational work, he would have carried his already brilliant career to still greater heights.

He presided over the Engineering School at Cambridge, and was doing splendid work there; he was also exceedingly popular with the students. The author well remembers, some time before the war, going down to Cambridge in order to see him carry out a number of interesting explosive tests on various types of ordinary and special steel plates, prepared by the author's firm. As a matter of detail it may be added that we not only blew our specimens to pieces, but nearly succeeded in accomplishing the same feat with regard to ourselves. That interesting paper of Professor Hopkinson's, "The Pressure of a Blow," in which some of the experiments mentioned are detailed, was a classic one and greatly added to our knowledge on the subject.

The time expended, and knowledge gained, bore good fruit, for much of the work carried out proved afterwards to be of great assistance to Hopkinson when helping to work out that vital problem for the Admirality, of how best to protect our battleships from the destructive, explosive effect of torpedoes. This was finally accomplished by means of the bulge attachment, designed by Sir E. Tennyson d'Eyncourt.

"Thorough and true" was indeed Bertram Hopkinson's maxim, as exemplified by his life's work; let this be ours, too.

Scientific Work Essential.—In metallurgy a great deal of scientific work has necessarily preceded industrial application. The same may be said of some other branches of science, but not of all. For example, electrical science and its development have originated almost entirely from the work of men of science;

whereas the work of George and Robert Stephenson in the development of the steam locomotive and railway is a notable example of practical development preceding scientific investigation.

From what has already been said, and from the facts stated in other parts of this book, it will be realised that the rise and development of alloy steels have depended essentially upon systematic scientific research. By no other means could their characteristics and possibilities have been determined accurately and completely.

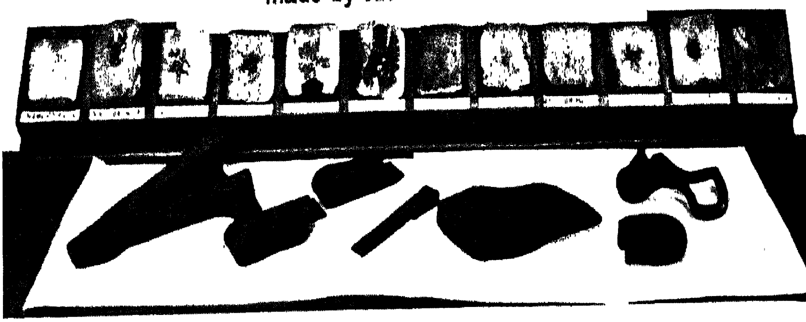
The two steels, silicon and manganese steel, like other developments in this field, could hardly have occurred without the preliminary investigations carried out by those with scientific training, supplemented by the work of men of practical experience. Just where the greatest credit lies in the final application to practice, it is sometimes difficult to decide.

It must not, however, be overlooked that the scientist often precedes his time, and that it requires the inventor to make his discoveries practically possible.

In these days, when alloy steels are used in such large quantities and for so many different purposes, with such striking results, it is most desirable that every engineer should have at least a general knowledge of their composition and properties. An excellent introductory treatment of the subject is to be found in the little book entitled "Special Steels," by Mr. T. H. Burnham, published by Messrs. Pitman, and this work may profitably be read as a preliminary to the study of more advanced treatises and specialised papers.

Alloy combinations, whether of iron or other elements, offer an enormously wide field for research, and it is quite possible that the future still holds many surprises as regards the results to be obtained. It is certain, however, that in the future, as in the past, the discovery of new alloys and their development can only arise from co-ordinated scientific research.

SPECIMENS FROM THE ORIGINAL
IRON MANGANESE ALLOY INGOTS
made by HADFIELD in 1882,



GROUP OF MANGANESE STEEL SPECIMENS
EXHIBITED AT THE INSTITUTION OF CIVIL ENGINEERS IN 1888.

CHAPTER VII

MANGANESE STEEL.

Main Properties of Manganese Steel. Though most steels in common use contain a small percentage of manganese, the term "manganese steel" is now generally understood to refer to an alloy steel containing 11 to 14 per cent. of manganese and from 1 to 1·5 per cent. of carbon. This alloy, discovered by the author in 1882 as a result of the researches described in Chapter VI, was the first malleable, non-magnetic ferrous product to be discovered, and it made available a combination of mechanical properties possessed by no other material. Each of the distinctive properties of the alloy has proved to be of practical value, and some of them are diametrically opposed to those of other steels.

The original iron-manganese alloy ingots, illustrated in Plate XV, were made by the author in 1882 and these—together with the group of manganese steel specimens as arranged for exhibition at the Institution of Civil Engineers in 1888, when the author's first papers were read—show the wide extent of this early research. Reading from left to right along the line of fractured ingots, the percentages of carbon and manganese are:

Carbon	0·20	0·40	0·47	—	—	1·01	—	0·95	0·85	1·26	1·10	2·10
Manganese	0·83	3·89	7·22	7·50	9·20	9·37	9·83	10·11	10·60	14·01	14·48	21·69

The most striking peculiarities of manganese steel may be summarised as follows:

(*a*) Manganese steel is practically non-magnetic, notwithstanding the fact that it contains about 86 per cent. of iron.

(*b*) The alloy is greatly toughened by quenching instead of being hardened and made comparatively brittle, as is the case with carbon steel.

(*c*) It has high tensile strength (60 to 70 tons per sq. in. when suitably heat-treated) combined with an extraordinary elongation, viz. 50 or even 70 per cent., exceeding that obtainable with the purest iron.

(*d*) Its resistance to wear by abrasion is greater, the more severe the service to which it is applied.

A material combining these and other remarkable properties has naturally found many important applications, and its discovery speedily attracted attention to the possibilities of other alloy steels. It is interesting to recall, however, that the properties of manganese steel involved further research to discover how the material could satisfactorily be worked; also the extraordinary nature of those properties delayed, for a time, a full appreciation by engineers of the purposes to which the alloy could be applied. Whereas engineers sometimes demand properties which cannot be obtained in any existing material, it is, on the other hand, not easy to determine and develop all the applications for a radically new material. The research worker is often faced by many difficulties after his initial or basic success has been achieved.

Casting, Forging and Rolling Manganese Steel.—In regard to its fluidity and ability to fill moulds of intricate shape, manganese steel resembles cast-iron. The medallions illustrated on Plate XVI demonstrate its qualities in this respect. A noticeable feature of all these medallions is the particularly sharp and clear impression, which is the more remarkable when it is borne in mind that the fluid manganese steel is poured at about 1450° C., compared with 1200° C. in the case of cast-iron, and has thus a much greater tendency to fuse the sand on the surface of the mould. The contraction of manganese steel is rather greater than that of ordinary steels, amounting to from 0·30 to 0·33 in. per foot, and the castings are particularly free from blowholes.

As might be expected from its characteristic properties, manganese steel is difficult to roll or forge in any but plain or simple forms. Nevertheless, experience in the manipulation and control of the material and its heat treatment has made it possible to produce successfully rails, sheets, plates, and even complicated assemblies, such as layouts, including points and crossings for railways and tramways, both of cast and rolled types.

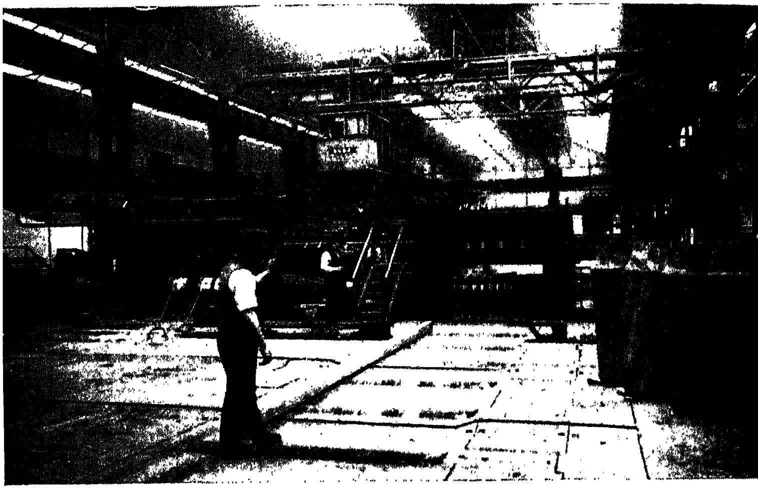
Manganese steel may be drawn into wire, but considerable difficulties are experienced, and the field for application for this particular product is limited.

Whilst it is commercially impracticable to machine manganese steel, it is often found possible to arrange the castings or forgings so that they can be used without any tooling. In other cases the parts are surfaced by grinding, and where links, wheels, pulleys, gearing, and other products are concerned, mild steel bushes

THESE MEDALLIONS WERE CAST FROM MANGANESE STEEL AND PRESENTED BY THE AUTHOR OF THIS BOOK AS A CENTENARY GIFT IN 1924 TO THE FRANKLIN INSTITUTE OF PHILADELPHIA, PA. (U.S.A.)

THESE SPECIMENS OF THE STEEL FOUNDER'S ART WERE CAST AT THE WORKS OF MESSRS. HADFIELDS LTD., SHEFFIELD.

The Fluid Steel from which these castings are made possesses the high temperature of about 1470° C. (2680° F.) yet sharp clear impressions in the castings have been obtained.



Reversing 28-in Blooming and Finishing Mill.

are cast into the article and machined in the usual manner. By these means, and others, which have been evolved to meet special requirements, manganese steel can be employed with entire satisfaction in all the applications where its use is desired.

The reversing 28-in. blooming and finishing mill, shown in Plate XVII, is believed to be the first one put down having for one of its main objects the production of manganese steel rails. This mill is capable of reducing 15-in. square steel ingots, 5 ft. long and weighing 25 cwts., to $2\frac{1}{2}$ in. square billets in a single heat. The normal output of such a mill, when working on ordinary steel, is about 1,500 tons per week; but on hard and difficult alloy steels this total is reduced enormously, for these materials cannot be rushed through in the same manner as carbon steel. Moreover, all the appliances and treatments necessary involve time and reduce the output. Manganese steel ingots are rolled into rails, up to the heaviest section in demand and up to 55 ft. in length. The hydraulic shears, used in conjunction with the mill are capable of shearing manganese steel blooms, when hot, up to 10 in. square. The total weight of the mill is about 1,600 tons, including the driving motor, which is rated at 3,200 h.p., and it is capable of developing 11,600 h.p. for short periods.

Heat Treatment of Manganese Steel.—As further explained in Chapter IX, both quenching and annealing produce, in manganese steel, effects opposite to those obtained in most other steels; quenching making the alloy tough, ductile, and non-magnetic—whilst annealing makes it hard, brittle, and magnetic.

In order to secure maximum toughness and ductility, manganese steel is quenched, preferably in water from high temperatures, 950° to 1,100° C. It is a curious fact that the rate of heating, the maximum temperature reached, and the rate of cooling, may all be varied within wide limits, without the appearance of any critical points or any changes in the general form of the heating and cooling curves. In other words, these curves afford no guide to the heat treatment of the alloy, as in the case of ordinary and other alloy steels, and offer no clue concerning the occurrence and mechanism of the remarkable change in structure by which the material, initially brittle, is made after quenching more ductile than any other alloy steel. The actual changes in structure between the steel, either as cast or as forged and the same steel as toughened after heating

to a high temperature and water quenching, is easily observed by aid of the microscope. It is then found that after being water quenched the toughened material has a purely austenitic structure, the carbon being in complete solution. This is shown by Figs. *A* and *B*, Plate XVIII. Futher information concerning heating and cooling curves of manganese steel is given in Chapter IX.

A particularly interesting feature of manganese steel is the extraordinary effect produced upon its toughness by heating to comparatively low temperatures. In a research made quite recently, the following important results were obtained.

Manganese steel in its toughened condition, that is, after quenching, possesses a yield point of about 26 tons per square inch; maximum stress from 68 to 72 tons per square inch; with no less than 60 to 70% elongation on 6 in.; reduction of area, 50%. The Brinell ball hardness number is about 230, and the specific magnetism, with iron as 100, under 0·10%.

When heated to and soaked at a temperature of 400° C. for one hour, its yield point becomes 25 tons per sq. in.; maximum stress, 64 tons per sq. in.; elongation 46% on 6 in.; reduction of area, 38%. The Brinell ball hardness, and the specific magnetism, remain about the same as in the original condition. It will be noticed there is a considerable diminution in toughness.

The same material, however, after being soaked for three hours at a temperature of 450° C. and cooled in air, is found to be brittle. It shows a yield point of 36 tons per sq. in.; maximum stress 58 tons per sq. in.; with only 2% elongation on 6 in., and about 4% reduction of area. The Brinell ball hardness rises to about 300, but the specific magnetism still remains under 0·10%.

By continuing the soaking for sixty hours, the material is made still more brittle, and quite magnetic, namely, 40 to 52 specific magnetism, as compared with 100 for Swedish charcoal iron. By chemical analysis and microscopical examination, it is found that these changes in character are due to the deposition of a double carbide of iron and manganese in acicular form. This double carbide is harder than the matrix, and is the principal cause of the hardness of the annealed product. Concerning the remarkable increase in the magnetic susceptibility of the material, however, no entirely satisfactory explanation can yet be offered.

If this "annealed" material be reheated to a high temperature and quenched in water, its heating curve shows a critical

point at 670° C., where the double carbide commences to redissolve, and the full toughness, ductility, and non-magnetic qualities are entirely regained in the quenched product.

The above is specially interesting because, during the war, when our soldiers wore " tin hats " made of manganese steel, the author was one day horrified to see in the illustrated papers a picture of a Tommy boiling tea or frying bacon in his " tin hat." As the foregoing tests show, he thereby risked de-toughening the material and causing the steel to be entirely inefficient to save his life if shrapnel bullets struck the helmet at high velocity. The attention of the authorities was at once drawn to the matter, and orders were issued to those at the front to see that on no account were the helmets to be in any way heated, and thus de-toughened.

The superior protection afforded by the British helmets of toughened manganese steel, compared with the French and German helmets used during the war, is shown clearly by the photographs reproduced on Plate XIX. About six million helmets of manganese steel were made during the war, and this material was also used for body-guards and leg protection. Tens of thousands of lives were saved in this way, and severe wounds were avoided in many more cases. From the humanitarian point of view this is probably one of the most important applications of manganese steel, but it must be admitted that, when discovering this alloy steel, the author had no idea that he would live to see the day when millions of his fellow-men would adorn and protect their heads with this wonderful material.

The " cold-treatment " of manganese steel at temperatures down to that of liquid hydrogen (– 250° C. or only 23° above absolute zero) reveals further remarkable properties of this alloy, for its non-magnetic character is retained and, though its ductility—like that of many other steels—is almost destroyed at this low temperature, the material regains its original toughness and ductility directly the temperature is returned to normal. So far as can be ascertained by microscopical examination, there is no change in its structure at low temperatures.

Hardness of Manganese Steel and Resistance to Wear.—In its undeformed state manganese steel is relatively soft, its hardness being then about 200 as measured by the Brinell test, but the material gains greatly in hardness under mechanical deformation, the Brinell hardness number then

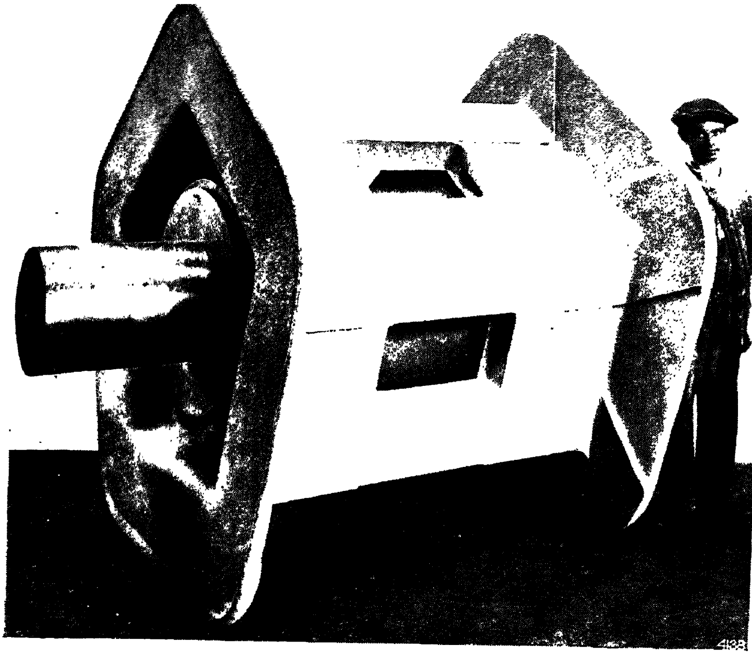
rising to 550 or 580, close up to the hard condition known as glass-scratching hardness of about 600 ball number. Therein lies the secret of the extraordinary durability of manganese steel; this curious phenomenon, for such it is, as no other known material behaves in this manner, was first noticed by the late Professor Osmond, with whom the author carried out important collaborative experiments extending over many years.

Even the slightest deformation of an article made of manganese steel is accompanied by a considerable increase in its hardness so that the highest wear-resisting qualities are developed only under the hardest working conditions. This peculiarity makes manganese steel pre-eminently suitable for the jaws of stone and ore crushing machines, dredger pins, bushes, lips, and other parts, tramway and railway points and crossings, and many other services subjected to abnormal stress. Also it explains why crusher jaws of manganese steel are actually less durable when dealing with sharp, friable material than when crushing refractory material, the very resistance of which develops maximum hardness in the working surfaces of the jaws. For the same reason, manganese steel parts can be surfaced by grinding but not by machining; the cutting action of the abrasive wheel removes innumerable small chips without abnormal hardening of the metal, whereas the tool of a lathe, planer, milling or other machine, hardens the material to such an extent as to make it practically unworkable.

The photographs reproduced on Plate XX are instructive. The upper illustration shows a dredger tumbler of manganese steel fitted on a shaft of 31 inches diameter; whilst the lower illustration shows the front and back of a colliery wheel made of manganese steel and bent under a steam hammer. This photograph affords an excellent example of the remarkable toughness of this alloy which is, at the same time, so hard that it cannot be machined.

Manganese Steel Track-work.—One of the most important applications of manganese steel is in the construction of layouts for tramway and railway crossings. Many of the congested junctions which are now operated successfully by the use of manganese steel track-work would be impracticable were ordinary steel employed, for the latter would be quite unable to withstand the severe conditions of service.

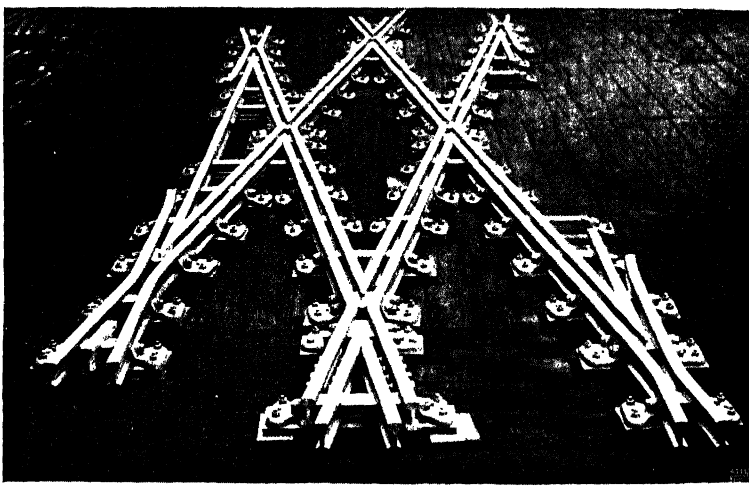
One of the most striking instances of the wonderful wearing qualities of manganese steel is to be found in the special layout



DREDGER TUMBLER OF MANGANESE STEEL.

COLLIERY WHEEL OF MANGANESE STEEL
BENT UNDER A STEAM HAMMER.

A Manganese Steel Tramway Rail and Crossing which were in continuous use for over twelve years at Sheffield.



A Specially Constructed Railway Crossover made entirely of Manganese Steel.

made by the author's firm for the Sheffield Corporation Tramways in Fitzalan Square. Nearly all of the cars on the system pass over this layout, which is in the centre of the City. The carbon steel rails and other parts formerly employed had to be renewed every few months, in fact, in some cases, every few weeks, so severe was the service. The first manganese steel layout installed at this place was in service for six years, and was then good for several years' further service, but additional tracks were required to accommodate the increased traffic. A larger layout, of manganese steel, was therefore installed in

TABLE VI.—DATA CONCERNING MANGANESE STEEL LAYOUTS IN HEAVY TRAMWAY SERVICE.

	First Layout Laid Sept., 1901 Replaced Sept., 1907	Second Layout Laid Sept., 1907 Replaced May, 1919
Average number of cars per day ..	2,700	3,510
Tonnage per day	27,000	30,000
Maximum vertical tread wear per 10,000 Cars..	0·0021 in.	0·0028 in.
Total vertical tread wear	0·484 in.	0·781 in.
Total number of cars that passed over the junction	5,225,000	13,500,000
Number of points	8	16
Number of crossings	18	28
Number of intersections	28	40
Number of rails	47	59
Number of years' wear	6	12
Total weight of layout	20 tons	33 tons

1907, and this lasted for twelve years, i.e., as regards the most severely tested portion of the layout, for forty-eight times the life of the carbon steel layout, notwithstanding the much heavier traffic of recent years. An average of 3,510 cars, with a total weight of 30,000 tons, per day passed over the layout during the period 1907–1919, or a total of 13,500,000 cars. Under this heavy traffic the manganese steel becomes intensely hard on the wearing surface, and this property, together with its toughness, is responsible for the remarkable durability attained.

Further particulars concerning these two layouts are given in Table VI, and Plate XXI shows one of the manganese steel rails *A* and a manganese steel crossing *B*, after continuous use

for twelve years in the Fitzalan Square junction. During this period the estimated number of cars passing over the layout was 13,500,000, which is equivalent to about 137,000,000 tons, to say nothing of the heavy loads imposed by other traffic at this busy centre.

The comparatively small wear produced is shown by the following data :—

	Lb.
The weight of the crossing when put into use was	1,005
,, ,, removed was	868
material worn away was ..	137
rail when put into use was	742
,, ,, removed was ..	616
material worn away was ..	126

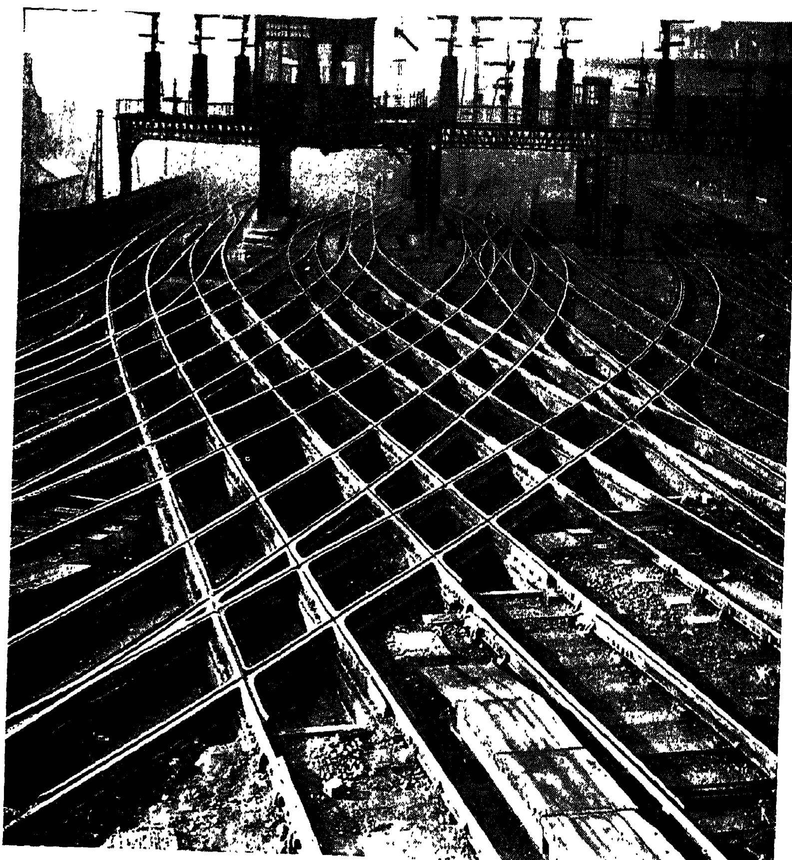
Another example of the use of manganese steel is for the construction of railway track-work, where this material has proved to be of great service in connection with layouts and intersections consisting of points, crossings, and other parts. Plate XXII shows one of these layouts in service on the London and North Eastern Railway, at the Central Station, Newcastle-on-Tyne. There are no fewer than 71 crossings and 21 rail castings, covering 77 intersections, the length of the junction being 141 feet, and the width over-all 58 feet, the total weight amounting to about seventy tons. This junction was put to work on October 30th, 1912, and was in use until 1924. It rendered a total service of about twelve years, whereas the previous construction made up of carbon steel rails gave only four or five years service, with constant replacements involving stoppages, inconvenience and great expense. Thus in comparison, nearly three times the life of this junction was obtained from manganese steel.

The total number of trains and the tonnages which passed over this layout during the period of twelve years, work out approximately as follows: Passenger trains, ¾ million; goods trains, 2¾ millions; that is a total of 3½ million trains, representing a total tonnage of 1,240 million tons. The passenger service included the heavy express trains travelling at high speed between London and Edinburgh.

On electric railways, owing to almost continuous train service, the wheels being smaller in diameter than on steam railways, rapid acceleration and stoppage of trains, and the increased number of driving wheels per train, the working conditions are generally more severe than at the worst positions

THIS PHOTOGRAPH REPRESENTS AN IMPORTANT JUNCTION AT THE CENTRAL STATION, NEWCASTLE-UPON-TYNE, ON THE LONDON AND NORTH EASTERN RAILWAY.

IT IS CONSTRUCTED ENTIRELY OF MANGANESE STEEL AND CONSISTS OF 71 CROSSINGS, COMPRISING 77 INTERSECTIONS AND 21 RAILS.
TOTAL WEIGHT, 70 TONS.



on steam operated railways. Consequently considerable and growing use has been made of manganese steel for the tracks of these, also with great advantage on the score of economy in cost of renewals and avoidance of inconvenience and disorganising delays to traffic incidental to replacing worn rails or points and crossings.

The history of the development of the use of manganese steel for track-work is in itself of considerable interest. The difficulties, both in manufacture and in application, always associated with the introduction of a new material, were met with and required considerable study as to the means of overcoming them. With use and experience, and the valued assistance of tramway and railway engineers, all these have been successfully overcome and a practice built up on the best lines. One of the difficulties experienced on electric traction systems arose from the high electrical resistance of manganese steel which demanded special bonding to reduce the pressure gradients across the layout, and to comply with Board of Trade regulations on this point. The practice successfully adopted is to bond the separate joints in the usual way, bushes or ferrules of mild steel being let into the web of the point, crossing or curve, to provide a means of attachment for the copper bond. In addition the whole layout is provided with a continuous bond from one end to the other, this having its attachment in the webs of the abutting rails of ordinary steel.

In certain cases the non-magnetic nature of manganese steel—a desirable characteristic in other directions—proved a difficulty in the use of the magnetic brake. Where it is desired not to forego either the advantages of the magnetic brake or the benefits of the use of manganese steel, compromise can be effected by the joint use of manganese steel and of ordinary steel in the layout so that the question of wear is solved, and, at the same time, a continuous track is provided for the operation of the magnetic brake.

It has been possible to standardise the design of the component parts of layouts, particularly in the case of switches, to a considerable extent, and this secures economy in manufacture. Even the largest layouts are all assembled and fitted together at the works (see Plate XXI), taking care of any gradients involved, ensuring their final assembly and putting into position on the site for which they are intended with a minimum of

time and trouble, a point of considerable importance in avoiding undue disturbance to traffic.

Rolled Manganese Steel Rails.—While track-work in manganese steel has been largely concerned with this material in the cast form, there is already a considerable demand for rolled rails and for layouts built up from rolled sections, particularly in connection with electric railways and for steam railways where the traffic conditions are heavy.

The economy in the use of rolled manganese steel rails is well illustrated by figures obtained from actual records on an important railway abroad on main line service with heavy traffic. In one instance manganese steel gave a life of 88 months as compared with 18 months for ordinary steel, the traffic passing over amounting to 315 and 58½ million tons respectively. The curves in this case were of 6 deg. In another case the respective periods were 62 months as against 12 months, with traffic figures of 116 and 19 million tons respectively. The curves here were sharper, viz., 9 deg. At still another point where the curves were exceptionally sharp—namely, 10 deg.—the life of manganese steel rails was 84 months as against 16 months for carbon steel, the amounts of traffic during the two periods being 216 million and 36 million tons respectively. Thus it is clearly demonstrated that rolled rails of manganese steel, in positions as on curves and with heavy traffic, outlast ordinary steel rails in the proportion of five or six to one. In certain cases figures show a still greater ratio, up to as much as eight to one. The above results have been obtained with rails of the heavy section, 105 lb. per yard, commonly used in America where the wheel loads are greater than in the United Kingdom.

Other Properties and Applications of Manganese Steel.—The mechanical properties of manganese steel which render it so valuable in the construction of special track-work, rock-crushing machinery, and dredgers, led to its being used during the war for certain kinds of sprockets and gears in the famous "Tanks," this being the only material which enabled such parts of these machines to stand the enormously severe wear and tear to which they were subjected.

As already noted, water-quenched manganese steel is practically non-magnetic, and for this reason it has been used in armoured and other structures near the magnetic compass in ships and aeroplanes. It was also used, towards the end

of the war, in the construction of sea mines. By making a considerable portion of the mines of this non-magnetic material of high tenacity, the enemy was prevented from detecting their presence, as he could easily have done had they been made of ordinary iron or steel; there were also other advantages which cannot be mentioned here. Great credit is due to one of the Fellows of the Royal Society, Professor J. C. McLennan, who for a long time worked strenuously night and day upon the problem until this mine was made successfully.

The electrical resistance of manganese steel is 71 microhms per centimetre-cube, or seven times that of pure iron; the average thermal conductivity between 0° and 100° C. is 0·027 C.G.S. units, or about one-sixth that of pure iron; and the mean coefficient of expansion between 0° and 100° C. is 0·000018 per 1° C., or about $1\frac{1}{2}$ times that of pure iron. The fact that these properties are combined with the non-magnetic and mechanical characteristics already noted, makes manganese steel useful in special applications too numerous to mention. Doubtless yet other applications will be discovered from time to time.

CHAPTER VIII

SILICON STEEL.

The Element Silicon.—In view of the importance of silicon in metallurgy, it is desirable, before proceeding to the description of silicon steel, to refer briefly to the element silicon itself.

It has been stated by some authorities that Sir Humphry Davy was, in 1807, the first to separate the non-metallic element silicon, whilst others claim that Berzelius first isolated it in 1810.

According to certain authorities, for example, "Cyclopædic Science Simplified," published in 1869, carbon, silicon and boron were each obtainable in three conditions, amorphous, graphitic and crystalline. On the other hand, in the excellent and modern book on "Inorganic Chemistry" by Dr. T. Martin Lowry, F.R.S., mention is made of only two forms of silicon, namely, brown amorphous silicon with a density of about 2·35, and crystals of metallic silicon, with a rather higher density, namely, about 2·50.

Boron in the fused product resembles crystalline or metallic silicon.

Carbon exists in three allotropic forms, as charcoal, graphite, and diamond. Graphite and diamond are crystalline substances of definite composition, but charcoal is a crude product which is very difficult to purify, except under conditions which cause it to change into graphite.

Silicon is one of the elements on the border-line between metals and non-metals. The distinctions between these two classifications is sometimes not very clear or exact; they seem to overlap. Thus, this element, the oxide of which forms an acid body, is therefore called a non-metal: nevertheless, the crystalline form has a steely metallic lustre, and an electrical conductivity between that of bismuth and that of arsenic or antimony. Silicon also freely dissolves in metals. From some of these, e.g. aluminium and silver, it crystallises out unchanged;

whilst with others, e.g. iron, it forms silicides. On the other hand, aluminium is generally accepted as a metal, although its oxide, whilst in some compounds behaving as a base, in others behaves as an acid.

The atomic numbers of boron and carbon are respectively 5 and 6, those of silicon and aluminium 13 and 14: the atomic weights being boron 10·9, carbon 12·005, aluminium 27·1, silicon 28·10.

According to a modern form of the periodic classification of the elements as given in Lowry's work referred to above, aluminium falls under boron in column III, whilst silicon falls under carbon in column IV. This is the most recent form of Mendeléeff's Periodic Table, and there is a marked family relationship exhibited between members of each vertical column.

Atomic numbers depend on a regular progression which has been discovered in the frequency of the radiation given out when the different elements are used as the anti-cathode of an X-ray tube.

From the foregoing it will be seen that there is some fundamental relationship between these four elements, which may explain their obvious points of similarity.

The chief points of resemblance between silicon and aluminium are (1) close similarity of atomic number and atomic weight: (2) density, silicon approximately 2·50, aluminium 2·66: (3) heat of oxidation, calories per gram atom of oxygen, silicon 90,000, aluminium 130,000, both high: hence they are generally found as oxides in nature: (4) neither of the oxides show strongly acid or basic properties, silica forms a weak acid whilst alumina is amphoteric, i.e. it can assume either rôle: (5) both confer "soundness" on iron, a very important property, because of their affinity for oxygen, which is always present in metallurgical processes.

In several respects, singular to say, silicon possesses metallurgical properties like aluminium, which is, however, a metal, whereas silicon is a non-metal. There is some hidden mystery here which, perhaps, X-ray examination will ultimately reveal to us. As is well known, the element in its chemical compound silica, forms a large portion of the earth's crust.

The physical constants of silicon are: atomic weight 28·10: atomic volume 11·60: density, grams per cubic centimetre, 2·50: melting-point, degrees Centigrade, 1,420:

linear coefficient of thermal expansion per degree Centigrade $\times 10^{-6}$, 0°–100° C., 7·63: specific heat, calories per gram per degree Centigrade at room temperature, 0·17: electrical resistivity, microhms per centimetre-cube, 58: type of crystal lattice, tetrahedral cubic: lattice constant side of elementary cube or hexagon, Å, 5·43: closest approach of atoms, Å (1Å=10^{-8} cm.), 2·35.

Since writing this section the following important experiments have been made, and an account of them seems advisable in order to complete the knowledge on this subject.

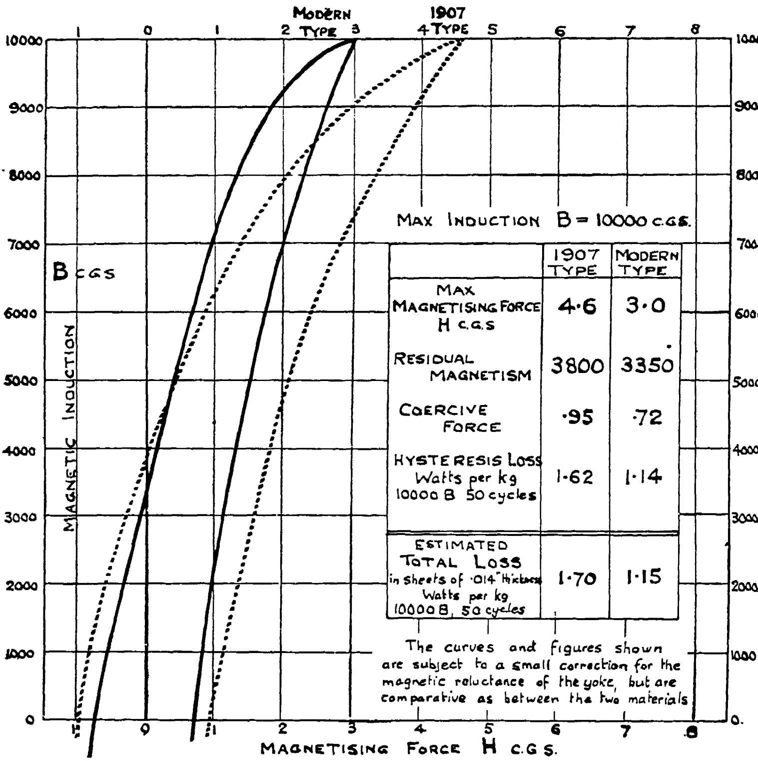
A short time ago the author furnished the necessary materials for the production of an alloy of iron and silicon of exceptional type having the following composition:—·015 C; 3·53 Si; ·008 S; ·015 P; ·03 Mn; ·011 Al. This was melted and produced for him by the kind permission of the Sheffield University authorities in a small high frequency furnace. During the melting the furnace was sealed and the internal pressure reduced to 1½ inches of mercury by means of a Geryk pump operating continuously. The molten material was allowed to solidify and cool outright in the furnace, the ingot obtained weighing about 9 lbs. Its Brinell hardness in the untreated condition was 212. Fracture showed it to be quite sound with the typical coarsely crystalline structure of silicon steel with low carbon content, to an enhanced degree, the crystal grains being particularly large.

Half the ingot was heated to 1000° Centigrade and was forged with very little difficulty into a bar ½ inch in diameter, 4 feet long. The forgeability of silicon steel, to those unaccustomed to its qualities, is usually a matter for some surprise, as the coarsely crystalline character rather leads to the expectation that under the influence of mechanical working it would fall to pieces. However, such is not the case.

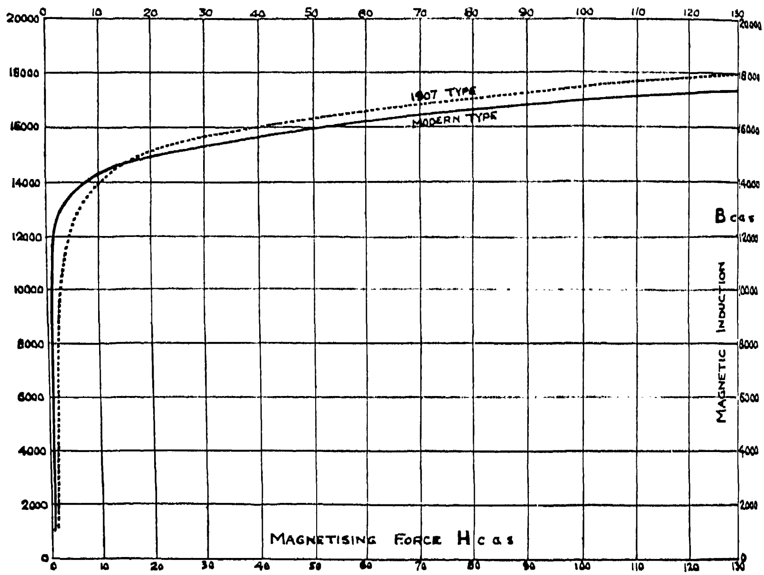
A portion of the bar was annealed by heating it to 800° Centigrade and maintaining this temperature for 24 hours, afterwards cooling slowly in the furnace. In this annealed condition its electrical and magnetic qualities were determined. The electrical resistance at 18° Centigrade was 50 microhms per centimetre cube, this figure being in conformity with its silicon content.

The magnetic qualities are shown in plates XXIII and XXIV. It would have been desirable from the practical point of view to have made a direct determination of the total losses, but the

MAGNETIC HYSTERESIS OF MODERN SILICON STEEL
AS COMPARED WITH THE QUALITIES OBTAINABLE AT THE TIME OF ITS FIRST
APPLICATION ON A COMMERCIAL SCALE IN 1907.



MAGNETIC PERMEABILITY OF MODERN SILICON STEEL
AS COMPARED WITH THE QUALITIES OBTAINABLE AT THE TIME OF ITS FIRST APPLICATION ON A COMMERCIAL SCALE IN 1907.



amount of material available did not provide sufficient for reduction into sheet form for this purpose. The low hysteresis losses and high permeability of the material, however, sufficiently indicate its high magnetic quality, and lead to an estimated figure for the total losses of 1·15 watt per kilogramme for an induction of 10,000 C.G.S. units and a frequency of 50 cycles per second, in the form of sheets .014 inch in thickness.

It is interesting to compare, in Plates XXIII and XXIV, the qualities of this exceptional and purer type of material with those obtained from silicon steel at the time of its introduction in 1907 on a manufacturing scale. The silicon content was at that time also rather lower, namely about 3¼ per cent. The practical experience gained in the manufacture of this steel since that time, and the better understanding of its working qualities, have enabled the silicon content to be increased without rendering the material unduly difficult to manipulate, while at the same time achieving rather better magnetic qualities and higher electrical resistance with corresponding reduction in eddy current losses.

Micro-examination of this special material in the forged and annealed condition, in which it was tested magnetically, showed a clear ferrite grain structure with an average of 4,700 grains per square inch. Material of the 1907 type showed a much smaller grain structure, averaging about 80,000 grains per square inch. Examination of the crystal structure of this recent material by radiographic methods by Professor Honda is referred to on page 134 and heating and cooling curves showing its critical temperatures are also shown in Plate XXX.

Incidentally it may be of interest to add the following reference with regard to several very interesting and important researches in this same direction, carried out by Mr. T. D. Yensen. His first three papers were presented to the University of Illinois in March, 1914, March, 1915, and November, 1915, entitled respectively, "Magnetic and Other Properties of Electrolytic Iron melted in Vacuo"; "The Effect of Boron upon the Magnetic and other Properties of Electrolytic Iron melted in Vacuo"; and "Magnetic and other Properties of Iron-Silicon Alloys melted in Vacuo." Then followed in April, 1920, a paper on "Magnetic and Electrical properties of Iron-Nickel Alloys" read before the Boston Meeting of the American Institution of Electrical Engineers; in March, 1921,

an article on "The Development of Magnetic Materials" in the *Electric Journal*; and in February, 1924, "The Magnetic Properties of the Ternary Alloys, Fe-Si-C," before the Philadelphia Meeting of the American Institution of Electrical Engineers.

Those interested in the subject will find much valuable information described in these important researches, regarding the working out of which great credit is due to Mr. Yensen.

Whilst this book was going through the Press, the author heard with deep regret of the death of Sir William Barrett, whose research work on, and discovery of, the magnetic and electrical qualities of silicon and other low hysteresis steels has been gladly acknowledged.

In some cases, and perhaps in this, the lapse of time causes the world to forget the pioneer work of scientists, and as it is nearly a quarter of a century since the account of the discovery was given in the joint papers, referred to later in this Chapter, as having been read before the Royal Dublin Society and the Institution of Electrical Engineers, the publication of this book has afforded an opportunity of recalling the work of the deceased scientist to the public mind.

Early Experiments and the Invention of Silicon Steel.—Turning now to the description of the invention of silicon steel, it was in the year 1882 that the author's attention was specially directed to the effect of silicon on iron, owing to the following curious, and, as proved later, most important results.

In the foundry department at Hadfield's steel works in Sheffield, an order had been executed for a pair of cast steel rolling mill pinions for a local mill. These were duly supplied and put to work. After they had been in service for a short time, the user complained bitterly that his mill was requiring much more power to drive it than was normally the case, that the pinions were constantly "seizing," and, in fact, that the running of the pinions was as if sand had been poured between the teeth! An analysis was made, when it was discovered that over $1\frac{1}{2}\%$ of silicon was present in the steel, which had been brought about by the heat of steel under treatment not having been properly decarbonised and desiliconised. The pinions were replaced with steel of normal composition and nothing more was heard of the trouble. This incident, however, led the author to think that perhaps the particular quality of material in the pinions containing silicon

might be employed to advantage for other purposes. For instance, it seemed possible that such steel might be used in place of an emery wheel. Emery wheels in those early days were comparatively weak and, just about the same time as the above-mentioned incident of the pinions, an emery wheel used on a machine for grinding steel castings had burst into several pieces whilst revolving at a very high speed. As a result a hole was knocked through a brick wall and the broken portions finally landed on the bed in the room of one of the workpeople living close by. Fortunately this was in the daytime, so no one was there to be hurt, but the mishap showed the desirability of a stronger form of grinding wheel.

The author decided, therefore, to try and produce a cast grinding wheel or disc, making this from a curious kind of steel which was obtained by melting together steel scrap with silicon spiegel. This latter material was a ferrous alloy, then in itself quite newly introduced, and a raw product coming from the blast furnace. Such ferrous alloy contained high percentages of silicon and manganese. It was not malleable or useful for any practical purpose, except the important one of being the means of conveying these two elements, silicon and manganese, into the iron itself.

The steel, if such it could be called, resulting from these experiments, contained about 1·50% C, 4·00% Si, and 8·00% Mn, the rest being iron. The silicon was added for the reason mentioned, namely, that it was expected the presence of this element would result in a steel having the qualities of and capable of acting as an emery wheel; but, being much stronger, would not burst.

Whilst the experiment was practically a failure as regards its primary object, it had the remarkable result of leading to the discovery of both manganese steel and silicon steel. On full examination, and after making tests, it was found that the alloy resulting from the combination of these two elements, manganese and silicon, some carbon and the rest iron, was of no advantage and did not possess the qualities desired. The author therefore decided that it was desirable to try the effect of manganese alone and silicon alone, that is, each added to iron as separate elements, carbon being necessarily present to some extent. In the case of the manganese-iron alloy the ratio of the carbon present was about one-twelfth, that is, in ferro-manganese containing from 70 to

80% Mn there was about 6 to 7% C. In the case of the silicon-iron alloy, this varied in the ratio of about one-fifth to one-twentieth, according to the percentage of carbon existing in the particular type or quality of ferro-silicon employed.

These experiments, therefore, were really planned—though at the time the author did not appreciate that the results would prove or turn out to be what they did—to produce separately the two alloys now known as manganese steel and silicon steel.

Experiments were first made to ascertain what would be the effect of manganese upon iron or mild steel containing but little carbon. These tests resulted in the discovery of manganese steel on September 9th, 1882, under circumstances already described in Chapter VI, hence the following remarks have reference only to the corresponding experiments with silicon steel.

The research work in question had for its object to ascertain the effect of silicon upon iron, using various percentages of silicon—about two, three, and even more than four per cent. —far in excess of anything which had, to the author's knowledge, been proposed before, and to try the products for different purposes, both in the form of castings, forgings, and rolled work.

The experiments continued during the year 1883, and it was finally in 1884 when the author invented an iron-silicon alloy, low in carbon and containing from about 1·50 up to about 5·00 per cent. of silicon; and in 1885 silicon steel with higher carbon. These inventions were protected by patents obtained in 1884 and 1886.

The low carbon silicon iron alloy, known afterwards as "Silicon Steel," formed the basis from which, by later inventions, the author succeeded in producing this steel of the quality and type now so largely and successfully used in the electrical industry for the manufacture of electrical transformers and other apparatus. Much thought, time, and work were devoted to this type of alloy, and many tests, casts or mixtures were made with varying percentages of silicon, as well as a large number of mechanical and microscopic tests to ascertain the qualities of the steels for various purposes, discovering that they possessed valuable mechanical and other characteristics.

The results of the various research work on the alloys were embodied in a paper read by the author in 1889 before the Iron

and Steel Institute. In the same year he presented a report of his research work to a Special Committee of the British Association, which consisted of the late Sir William Roberts-Austen and Professor Tilden, the Secretary of the Committee being the author's friend, Professor T. Turner, of Birmingham University, who was also occupied from 1885 onwards in his researches on the effect of silicon upon cast-iron. Professor Turner presented important papers with regard to his researches, which afterwards proved to be of very considerable scientific and practical value, and with which his name is always rightly associated.

In these early researches relating to silicon steel containing both low and higher carbon, the author carried out at great cost and expenditure of time, more than one hundred separate steel experiments, as well as several thousand physical, chemical, and mechanical determinations.

Numerous manufacturing difficulties had to be overcome, and much time was spent in producing and ascertaining the qualities of even the ingots of small size used in these experiments. In the production of the larger masses which were required for industrial applications, as mentioned later, many further problems arose, for silicon steel, specially that with low carbon and without manganese, is difficult to produce, also to roll and heat-treat.

During the early stages of this research work, the author made several series of silicon-iron alloys by adding ferro-silicon to decarbonised and desiliconised iron. In one of these series, probably the earliest, the silicon percentages were as follows: No. 1, ·40; No. 2, ·81; No. 3, 1·23; No. 4, 1·65; No. 5, 2·11; No. 6, 4·00% Si. The sulphur and phosphorus were about ·05% each, manganese being only present in small percentages. In another series, the resulting composition was as follows: ·10 C, 3·17 Si, ·08 to ·10 S, ·09 P, ·18 to ·22 Mn %. In other specimens of this series the compositions were ·16 C, 4·43% Si; ·18 to ·20 C, and 8·83% Si. An interesting comparison between old and modern types of ferro-silicon is shown by Table VII.

The silicon iron alloys just mentioned, constituting silicon steel and containing both low and higher carbon, were produced as castings and forgings. In the form of a casting the author made an armour-piercing projectile of 9-inch calibre containing nearly one per cent. of silicon, which was fired at Shoeburyness

against a compound armour plate 11 inches in thickness, the striking velocity being 1539 f.s., and the energy 4200 foot-tons. The projectile, however, was found to be too soft, although this was probably not entirely the fault of the steel. In those days the knowledge of hardening special steels was comparatively small.

On the other hand, it was found that this type of steel forged satisfactorily, and that bars having a composition of about 0·70% of carbon and 1·53 to 3·00% of silicon and made into turning and other tools gave quite remarkable results when

Table VII.

Analyses of Ferro-Silicons.

	Analysis per cent.							
	C	Si	S	P	Mn	Al	Ti	Fe
(A) Older types 1882–1890								
The Wigan Coal and Iron Co.	2·70	6·20	·210	·030	·32	—	—	90·00
Darwen & Mostyn Co. ...	1·00	7·71	·050	·120	1·44	—	—	—
W. Dixon & Sons, Blantyre	1·70	10·25	·010	·160	2·20	—	—	—
	2·40	20·98	·040	·070	·72	—	—	84·00
Gjers Mills & Co.		15·60	·040	·060	4·46	—	—	—
		16·88	·030	·060	7·78	—	—	—
W. Dixon & Sons, Blantyre...	·90	18·10	·040	·090	·86	—	—	80·00
(B) Modern Types								
45% Ferro-Silicon		48·00	·020	·042	—	—	—	—
75% " "	·14	77·70	·028	·035	—	1·35	—	22·00
85% " "	·24	86·40	—	—	·02	3·11	—	10·20
Silicon Metal	·07	92·98	—	—	·30	1·00	·16	5·58

hardened and tempered, and this without the use of expensive Swedish iron. The following is the analysis of such tool steel made at the time mentioned :—Carbon, 0·74% ; silicon, 1·85% ; sulphur, 0·08% ; phosphorus, 0·08% ; manganese, 0·50%. According to a note made in the author's experimental book on February 6th, 1883, the head turner in the machine shop said that he had used one of these tools for three weeks constantly and it had behaved excellently. The experimental record adds "I will watch how this goes on."

This may be said to have really been the commencement of the use of silicon steel. This steel, thus first experimentally used in the author's works, was later adopted on a large scale, and is, in fact, still being employed. In addition to this use

of silicon steel by his own firm, and after the patents were obtained, the author was able, as the result of much uphill work, to convince sufficiently several steel-makers of its value for them to employ it in the manufacture of tool steel of the hardening type, that is, steel which possesses hardness obtained by quenching in water or oil. Many thousands of tons of this tool steel have been made by various licensees, amongst whom were well-known Sheffield firms. Although high-speed tool steel has since been developed and is used in large quantities, it has not entirely superseded other tool steels, including silicon steel, which is still preferred for certain classes of lathes and other tools in machine shops.

The author's inventions relating to the production of steel containing high percentages of silicon, in some cases with but little carbon and in others with higher carbon, were set forth in patents obtained in the years 1884 to 1886.

In this respect it may be mentioned that it was in 1888, when Professor Turner, of Mason College, Birmingham, read a paper at the meeting of the British Association held in Bath, which described experiments with steel containing comparatively small percentages of silicon, namely, from 0·10 to 0·50.

Further Researches.—The Committee appointed by this Association then asked the author to undertake a further research on the effect of higher percentages of silicon upon iron containing but little carbon, that is, representing those types of steel already covered by his own previous experimental work and by the early inventions already mentioned and patented in 1884 to 1886. In 1889 steels were made varying from 0·24 to 8·83% of silicon, the carbon being kept as low as possible; this was the series regarding which the author presented his paper to the Iron and Steel Institute in 1889, and was also the subject of a Report to the British Association later in the same year, previously mentioned.

This full series of specimens containing up to 8·83% of silicon, along with a similar series relating to manganese, aluminium and chromium, were exhibited at the Technical School, as it was then called, in Sheffield, at a Conversazione given by the author as the first President of the Sheffield Metallurgical Society, in 1893.

In these experiments, complete co-ordinated results, including chemical composition, mechanical qualities, comprising elastic

limit, yield point, tensile strength, elongation, reduction in area, and compression, were obtained. The relative hardness of the various specimens was also determined by Professor Turner by his "Scratch" method. The experiments were made on both (a) unannealed and (b) annealed forged materials. The effect of water quenching, compression tests, corrosion experiments, and specific gravities were also determined and set forth in the paper. This research proved to be of considerable and practical importance.

Early Opinions and Work of Other Metallurgists.—During the discussion on the paper to the Iron and Steel Institute in 1889, Monsieur Gautier, of the famous Terre Noire Company, mentioned that he had recently paid a visit to the Hadfield Works where he had been shown "some splendid tools made with silicon and carbon in which there was 1·50% silicon and about 0·50% of carbon."

Monsieur Gautier also added that he was sorry some of these specimens of tool steel were not exhibited at the meeting. In replying to the discussion the author pointed out that the specimens then exhibited—this was at the Paris Meeting of the Institute—were silicon steel containing practically no carbon, and were so made in order to ascertain the effect produced by silicon upon iron without other elements being present, or, when present, only in small quantities. Special attention is now called to this fact because, owing to these steels containing low carbon, some of them were afterwards found to be of important value for electrical purposes. This will be dealt with later.

In the subsequent discussion by correspondence, Monsieur Alexandre Pourcel, who is happily still with us and is one of the Honorary Vice-Presidents of the Iron and Steel Institute, referred to some experiments carried out in 1875, at the Terre Noire Works, on steels containing from 0·10 to 0·40% of silicon, and also to the use of silicon in steel castings that were exhibited at the 1878 Paris Exhibition.

It may here be stated that it was just about that time when Monsieur Ferdinand Gautier and his colleagues, Monsieur A. Pourcel and Monsieur Euverte, at the Terre Noire Works, were carrying out their great work of making and introducing to the world ferro-manganese and ferro-silicon alloys produced in the blast furnace, and so useful for many metallurgical processes in the manufacture of steel. These scientific

metallurgists at the Terre Noire Works were largely the means of introducing on a large scale the employment of similar percentages of silicon for the production of sound steel castings, that is from about 0·20 to 0·40%.

The wonderful exhibits of the Terre Noire Company at the Paris Exhibition of 1878 can never be forgotten. They were of the greatest value and instruction to all metallurgists, and represented a distinct step forward in the art of manufacturing sound steel and sound steel castings. It is often said by those who, perhaps, have not thought out the subject fully, that International Exhibitions are not desirable and that they disclose too much, also that, although we in this country started exhibitions, it was a great mistake on our part. Actually, however, we have probably learned just as much from exhibitions abroad as our friends from abroad have learned from exhibitions in England. Surely the exchange of ideas represents the general progress and advance of the world.

Much later on, other metallurgists realised the advantages to be obtained by the use of higher silicon in steel for various purposes. One of these was the employment of a comparatively small percentage of silicon, from about 0·25 to 0·50%, in steel rails, by the late Mr. Sandberg, followed by his sons, Messrs. C. P. and N. P. Sandberg, who have also paid special attention to this development.

Silicon Steel in Ship Construction.—That well-known metallurgist, the late Mr. John Spencer, used percentages of silicon up to about between 0·70 and 1·00, in mild carbon steel, with a view to obtaining high tenacity steel for ship plates. Great credit was due to Mr. Spencer for the way in which he worked to introduce this material, which gave high tenacity without reducing ductility. This particular application was also followed up by other steel makers, including Messrs. Colville.

In this connection it is interesting to mention that certain parts of the ill-fated *Lusitania*, as also of the *Mauretania*, whose recent wonderful journeys over the Atlantic have filled the world with astonishment, were constructed, on account of its higher tenacity, of this silicon steel, containing such a high percentage as would have made engineers of the last generation fear and tremble.

The following were the tests obtained from this steel used in the construction of the *Mauretania*, specimens of which were furnished to the author in 1907. The steel showed a

composition of carbon 0·27, silicon 1·12, sulphur 0·03, phosphorus 0·048, and manganese 0·72%. The tensile tests gave yield points of 28 to 30 tons per square inch; maximum stresses of from 41 to 47 tons per square inch; with elongation of 25 to 30% and reduction of area of 45 to 52%. The fractured tensile bars were fibrous silky half cup and ball, indicating the excellent quality of the material. The following were the shock qualities:—Nicked test-pieces of the Frémont type required an energy of 4·45 kg.-m. (32·0 ft. lbs.) to fracture, giving a bend of 13°; un-nicked specimens giving the corresponding figures 42 kg.-m. (304 ft.-lbs.) with a bend of 113°. Heat-treated specimens showed still higher figures.

Much valuable information was given in various papers read at the Shipbuilding Sections of the Engineering Conference held at the Institution of Civil Engineers in 1907, by Mr. A. E. Seaton, Mr. (now Sir) A. F. Yarrow, and Mr. E. W. de Rusett, on the subject of high tenacity steels as used for ships, bridges, and other constructions.

The silicon steel used for the *Lusitania* was made by Messrs. Colville, and that for the *Mauretania* by Messrs. Spencer, who stated that they had made satisfactory ingots up to 16 tons weight, with plates 38 feet in length by 7 feet 8 inches in width, by 1¼ inches in thickness.

This material was stated by Professor Barr, in "Engineering" of June 28th, 1907, to show a superiority of 64 per cent. over mild steel, whilst tests taken cross-wise showed a superiority of 94 per cent. over mild steel similarly tested. To satisfy Lloyds and the Board of Trade that the steel would resist shock or sudden impact, plates of high tensile steel 6 feet by 3 feet by 1 inch in thickness were placed on two supports 4 feet apart. Upon these a ball weighing 3 tons was dropped from varying heights, and finally from 31 feet, the result being simply buckling and no cracks of any kind. Another plate was afterwards doubled over flat, a particularly severe test, which the late Sir William White termed "brutal" treatment.

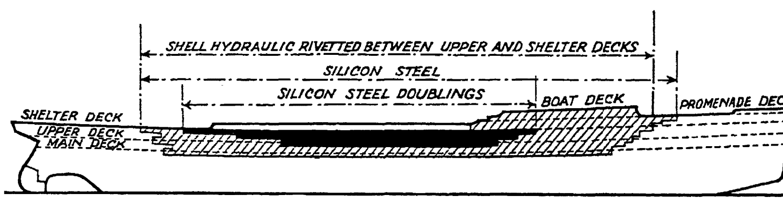
Finally, dynamite tests were made on several of these high tenacity ship plates in order to ascertain their capacity to resist sudden impact. Even after this test no fractures or cracks were to be seen in the plates.

Thus it was clearly proved that steel containing about one per cent. of silicon, quite contrary to the accepted beliefs then prevailing, possessed high qualities of resistance to severe

punishment including sudden shock, and that provided the carbon is not high, silicon does not confer brittleness upon iron as so many engineers and metallurgists had thought to be the case.

By the use of this silicon steel it was thus found possible to lighten considerably the upper deck structures—that is, to reduce the thickness of the scantlings—of these two steamships, both of which showed such wonderful voyage records.

The portions of these two great British ships in which silicon steel was employed are shown by the shaded sections in the following Figure, which was given in the paper on "The Use of High-Tensile Steel in the Construction of



THE HATCHED AND FULL BLACK SECTIONS REPRESENT THE SILICON STEEL SHIP PLATES USED.

the *Mauretania*," by Mr. Edwin William de Rusett, M.Inst. C.E., and is reproduced here by kind permission of the Institution of Civil Engineers. High-tensile silicon steel was used for the top sides and doublings, also for other parts on the shelter deck. A saving in weight of some 200 to 300 tons was thus effected, and yet at the same time there was obtained an appreciable increase in the strength of these upper structures. Mr. de Rusett thought that in the light of the tests obtained, a further reduction of 10% in the scantlings, making 20% in all, might reasonably have been made, as a fair margin of strength would still have been secured above the mild steel basis. The whole of the shell plating and other parts of the special steel were pickled to remove mill scale.

Whilst, of course, the main cause of the wonderful speed obtained was the splendid design work and engineering skill shown, yet it can be said that indirectly silicon steel was a useful additional, in fact, a material help in assisting the designers, ship-builders, and engineers in bringing about the wonderfully high speed of these two great steamships—British built, British material, and British manned, and so maintaining British prestige on the high seas. The *Mauretania* was built on the

Tyne by Messrs. Swan, Hunter, and Wigham Richardson, making her maiden voyage in November, 1907. In 1922 she was converted into an oil-burner. In one of her memorable voyages she left New York on Wednesday, August 20th, 1924, passed the Ambrose Channel Lightship at 3.53 p.m. Greenwich mean time, and reached Cherbourg at 5.42 p.m. on Monday, August 25th, having covered the intervening 3,198 miles in 5 days, 1 hour and 49 minutes. The three records she set up are as follows:—Average speed 26·26 knots; best day's run 626 miles; fastest eastward passage, 5 days, 1 hour, 49 minutes. The vessel's average speed thus works out at about 30 miles per hour.

The same ship had three successive eastward trips in 1923, with a difference of only five minutes in the time taken for the several voyages.

The voyage completed in August last was the *Mauretania's* 308th crossing of the Atlantic; she has steamed well over a million miles in the passenger service and carried more than 400,000 passengers.

In addition to the foregoing there have been many other applications of silicon, including the material known as silico-manganese steel, a composition of steel containing about 0·40% of carbon, 1·75% of silicon, and 0·90% of manganese. This steel is largely used for motor-car springs.

It should be pointed out that these later and special applications and employment of this steel relate to the use of comparatively small percentages of the element, about one per cent.; whereas in the author's silicon steels as used for electrical purposes, the percentages employed were up to three to four times higher, and conferred altogether different qualities.

With such evidence of the beneficial influence of silicon upon steel for many classes of products, at first sight it may seem difficult to understand why this element acquired the evil reputation it, at one time, undoubtedly had. One of the explanations is that in the early days most of the ferro-silicon obtainable was comparatively impure, high in carbon, and possessed other disadvantages. Another reason was that in those days it was not known how to manufacture or treat steel of such peculiar composition.

When the author commenced to study the effect of silicon upon iron, its presence was considered to be most harmful,

inducing brittleness and general inferiority. Specifications of that day for railway rails and railroad materials—in fact, down to a comparatively recent date—demanded most strictly that steel should not contain more than about 0·10% of silicon, or the products would be rejected. Occasionally 0·20% or 0·30% was used, but such steel was generally looked at with suspicion by most engineers. Many refused to accept or use such steel—in fact, its action was almost classed along with that of those injurious metalloids, sulphur and phosphorus.

In "A Practical Treatise on Metallurgy," by Crookes and Röhrig (1870), it was mentioned that Karsten, one of the leading metallurgical authorities of that time, stated that so small an amount of silicon as 0·05% modified the tenacity of the iron, and more so than an equal amount of sulphur and phosphorus. It was also stated that a harder steel for tools is made brittle by a small amount of silicon.

Gautier of Terre Noire was probably the first to discover that Karsten had in his remarks made the mistake of attributing to silicon what ought to have been attributed to silica, in the bad properties of wrought-iron.

Caron recommended the addition of manganese to the raw material as the best means of removing the silicon.

Jullien stated that silicon, if contained in cast steel, caused a considerable contraction on cooling, and also corroded the moulds.

These beliefs, many of which seem to-day trivial, expressed by the authorities above mentioned, all great metallurgists in their day, show how utterly wrong were the conclusions then arrived at. "Trial and error" methods had not been sufficiently employed, consequently wrong conclusions were drawn. Also, in those days, suitable ferro-alloys from which to produce the steel alloys were not available, thus adding to the difficulties.

The opinion that silicon was deleterious was wrong, not only as regards steel, but also, as so ably shown by Professor T. Turner, of the Birmingham University, in the case of cast-iron. The proper and scientific employment of silicon for many purposes was found to be most beneficial.

At the Essen works of Krupp, which the author occasionally visited, he was informed that silicon had been used in what was considered by them to be quite large percentages, that is to say, up to about 0·30% or 0·40%, and their metallurgists were

astonished when they heard of the excellent results which the author was able to obtain from steel containing much higher percentages, not only for one or two but for many special applications.

After so often finding out from experiments that this dread of silicon was unfounded, it was about 1882–1884 that the use of this element on quite a considerable scale, and in much larger percentages, was commenced in connection with the production of steel castings at the Hadfield works in Sheffield; that is, where others, such as the Terre Noire Company, used from about 0·16 to 0·32% of silicon, the author employed more than double this average percentage with great advantage for certain kinds of work, both in castings as well as forged and rolled material. This enabled not only greater soundness to be obtained, but also material with high durability.

The knowledge gained from these various researches was thus of great service in helping on the manufacture of sound steel castings on a large scale. Since 1883–1884 hundreds of thousands of tons of such steel have been produced, in which quite high percentages of silicon have been employed, thus ensuring for many purposes sounder and better steel than that made in the ordinary manner.

However, to describe the numerous uses of this formerly much-despised element silicon, in its many applications to ferrous metallurgy, including one of the most important of all —the reduction of the liability to unsoundness and blow-holes in steel—would take up far too much space. It is therefore proposed to confine the following remarks chiefly to the use of the element silicon as applied to the production of steels suitable for electrical purposes.

In this connection it may be mentioned that an American, Mr. John Kelly, of the Stanley Manufacturing Company, Pittsfield (Mass.), U.S.A., in 1896 took out both British and American patents covering a transformer core in which the percentage of silicon in the material employed was considered then to be unusually large. Kelly claimed he had found that a slight increase in the amount of silicon, not exceeding 0·03%, made the sheets more stable and reduced what he termed "hysteresis growth." One of the difficulties with the types of iron or mild steel used for electrical purposes at that date was the fact that the magnetising losses due to hysteresis, already very considerable and wasteful of energy, even in material which was

quite new or had been little used, often increased at a rapid rate, sometimes trebling in amount in the course of a few months. The discovery disclosed in this patent had reference to this secular change, or "ageing" as it is called, and it was claimed that the small addition of silicon mentioned had the effect of minimising the rate of deterioration or "hysteresis growth" of the material.

Special study of this phenomenon was also made by Mr. W. M. Mordey, afterwards President of the Institution of Electrical Engineers, who fully investigated its nature. He read a paper on the subject before the Royal Society in 1895, entitled "On Slow Changes in the Magnetic Permeability of Iron," giving the results of his research, which enabled him to determine the true cause of magnetic ageing. A further valuable paper was read by Mr. Mordey and Mr. A. G. Hansard at the British Association Meeting at Cambridge in 1904, entitled "Energy Losses in Magnetising Iron."

The use of silicon steel of high percentage provided a material with very much reduced initial hysteresis and eddy current losses, also possessing the quality of being almost completely non-ageing, and even in some cases inverting this undesirable characteristic, so as actually to become improved in use.

The late Dr. John Hopkinson was, it is believed, the first to deal with the effect of a comparatively high percentage of silicon upon iron, as regards its electrical and magnetic qualities. As recorded in his paper "On the Magnetisation of Iron," which appeared in the "Philosophical Transactions" of the Royal Society in 1885, he investigated in this way a number of different types of steel and iron, determining the electrical resistance, also the maximum magnetic induction, residual magnetism, coercive force, and energy dissipated through hysteresis.

Incidentally it may be mentioned that he there referred to a specimen, marked "X," of Hadfield manganese steel containing 1·20 carbon, 0·20 silicon, and 12·36% manganese, which he found to be practically non-magnetic. He also determined its electrical resistance which was about 65 microhms per centimetre-cube.

The silicon steel referred to and tested by him was of the following percentage composition—0·68 carbon, 3·43 silicon, 0·028 sulphur, 0·070 phosphorus, 0·69% manganese. In Part I of Table VIII, the results of Dr. Hopkinson's tests on this steel

are summarised in comparison with those of wrought-iron and mild steel tested at the same time. The analysis of the particular specimen of mild steel was :—0·09 carbon, no silicon, 0·016 sulphur, 0·042 phosphorus, 0·153% manganese. The wrought-iron specimen was not analysed.

To express these results according to present-day usage there is added in the last column an estimate of their total magnetisation losses, in terms familiar to constructors of electrical machinery. This estimate takes account both of the hysteresis losses, determined by Hopkinson, and also of the ohmic losses due to eddy currents, in which the electrical resistance, which he also determined, is the principal factor.

TABLE VIII.

TEST DATA RELATING TO SILICON STEEL, COMPARED WITH WROUGHT-IRON AND MILD STEEL.

Specimen No.	Material and Treatment	Specific Resistance Ohms per cm.–cube	Maximum induction	Residual induction	Coercive force	Energy dissipated	Estimated total losses Watts per lb. for B=10000 & 50 cycles
	Part I.						
XVII	Silicon Steel As forged ...	·00006063	15148	11073	9·49	45740	7·10
XVIII	" " Annealed ...	·00006185	14700	8149	7·80	36000	5·98
XIX	" " Oil hardened	·00006195	14696	8084	12·75	59000	6·27
I	Wrought Iron Annealed...	·00001378	18251	7248	2·30	13356	1·85
V	Whitworth Annealed ...	·00001080	19480	7080	1·63	10289	1·36
	Part II.						
A	Hadfield Silicon Steel as used in the original Transformer of 1903.	·000050	19500	8500	0·80	7150	0·72
B	Silicon Steel of present day quality.	·000060	19000	9000	0·60	4700	0·49

From the experimental data in Table VIII, it will be seen that Dr. Hopkinson was probably the first to discover the high electrical resistance, namely, 62 microhms per centimetre-cube, of the silicon steel above mentioned containing comparatively high carbon.

As will be noted, however, the hysteresis losses, and in consequence the total losses, were very considerable, as can now be readily explained by reference to the comparatively high carbon and manganese percentages in this particular specimen of silicon steel. Thus the qualities of low hysteresis and high

permeability were not present. It was not until the author's silicon steels with low carbon percentages had been made, and their electrical and magnetic qualities discovered by Sir William Barrett, F.R.S., after much patient research, to which reference is made later, that these important facts came to light. This quite distinctive advance is demonstrated by the comparative figures, which have been added in Part II of Table VIII, for silicon steel, both of the quality used in the author's original experiments and also as manufactured at the present day containing 3·75 to 4·00% silicon, and under 0·10% carbon.

To present the matter in another way, it may be mentioned that the electrical tests obtained by Dr. Hopkinson on the specimen of high carbon silicon steel, showed how inferior were its qualities for electrical purposes as compared with the silicon steel covered by the author's invention described in the patent of 1884, which was for silicon steel containing 1·50 to 5·00% of silicon, with low carbon.

In some communications and correspondence with Dr. J. Hopkinson in 1889, with regard to silicon steel, the author pointed out that the material which he had made contained very little carbon, thus making it possible to obtain useful conclusions as to the influence of the metalloid silicon upon metallic iron without other elements being present, or only to a small extent.

The tests, which have just been described, indicate this in a particularly clear manner, that is, they show that the beneficial influence of silicon on the magnetic qualities of iron was entirely masked by the sample with which Dr. Hopkinson experimented, containing too high percentages of carbon and manganese. This latter type of steel containing higher carbon was covered by another of the author's inventions, for which letters patent were obtained in 1885. Such silicon steel was found to be of great importance for tool steel and other purposes.

Electrical and Magnetic Qualities of Silicon Steel.—The extraordinary electrical and magnetic qualities of manganese steel, which was found to be non-magnetic and of high electrical resistance, had shown that useful and valuable characteristics of alloy steels might appear in most unlikely directions, and that therefore no new alloy could be considered to have had its possibilities sufficiently examined until it had been submitted to tests of the most varied nature possible, whether as regards chemical, physical, electrical, or magnetic properties.

In the early days, electrical and magnetic testing apparatus was comparatively scarce, and the author's laboratory was then equipped chiefly for metallurgical and chemical research. Later on, that is about 1902, there was installed the necessary apparatus for complete determinations of electrical and magnetic qualities. The author would like here to take the opportunity of expressing his heartiest thanks to Mr. S. A. Main, B.Sc., F.Inst.P., who since 1902 has been the head of this branch of the firm's Research Department, and has rendered such valuable assistance. It may be added that Mr. Main was trained under and recommended by Sir William Barrett, F.R.S., of the Royal College of Science, Dublin.

During the course of the author's experiments, Sir William Barrett, F.R.S., had taken particular interest in determining the electrical and magnetic properties of manganese steel, and of a steel alloy containing iron, manganese and nickel, known as "Resista"; also many other specimens, regarding some of which he contributed several papers to scientific institutions. From time to time, that is, from about 1887 and onwards, he tested a number of other steel alloys. These included the author's silicon steel, and a research was carried out by him with the co-operation of Mr. (later Professor) W. Brown, his able chief assistant, a former pupil of Lord Kelvin, by means of electrical and magnetic tests.

The author prepared in the form of rods about one hundred unannealed and annealed specimens of iron alloys containing various percentages of carbon, manganese, silicon, aluminium, chromium, tungsten, cobalt and copper, of the binary, ternary and quaternary types, in order that they should form the subject of a joint research relating to their electrical and magnetic characteristics.

The whole of these specimens were obtained from types of steel originated and made by the author over many years. Most of them were described in papers read before the Institution of Civil Engineers and the Iron and Steel Institute, both in 1888, entitled "Manganese Steel"; Iron and Steel Institute, 1889, on "Alloys of Iron and Silicon," 1890, "Alloys of Iron and Aluminium," and 1892, "Alloys of Iron and Chromium"; Institution of Civil Engineers, 1899, "Alloys of Iron and Nickel"; also other papers covering Alloys of Iron with Tungsten, Copper, and Cobalt. Many of these steels, including the silicon steels, were covered by patents.

The extremely complex nature of some of these alloys will be understood when it is borne in mind that in some cases there had to be considered the effect of not only the presence of, say, two special elements in addition to iron itself, but that the qualities of these were further modified in an extraordinary manner by the amount of the main "steel-making" element present, that is carbon. Moreover, in some cases, some of these alloys contained five elements, for example, carbon, silicon, manganese, chromium, and iron, and the quality of the steel produced might well be further profoundly influenced by the presence of such small percentages as ·05% or even less, of the deleterious elements sulphur and phosphorus. It will be seen that all this helps to confirm the important statement made at the World Power Conference in Mr. E. W. Rice, Jr.'s paper "New Fields of Research for Power Development," referred to elsewhere, as to the high complexity and the delicate nature of ferrous and non-ferrous alloys, also how easily their physical qualities are affected, not only by large percentages of added elements, which might be expected, but by even comparatively minute percentages of what may be termed foreign elements.

The author originated the compositions of his steel alloys, the foundation of any research of this kind, and undertook the preparation of the unannealed and annealed specimens, as also the mechanical, chemical, and certain other tests. In many cases the production was attended with great difficulty. The electrical and magnetic qualities of many of these alloy steels were investigated by Professor (now Sir) William Barrett, with the able help of Mr. W. Brown, B.Sc. The investigations extended over about eight years, and resulted in the discovery of the low hysteresis and high resistance qualities of the silicon and aluminium steels so prepared.

As a result of these research examinations, it was discovered that amongst the specimens investigated, these two alloys possessed remarkable electrical and magnetic qualities, which rendered them suitable for use in the manufacture of electrical transformers, if they could be successfully produced on a manufacturing scale.

The results of the investigations were embodied in joint papers by Barrett, Brown and Hadfield, read before the Royal Dublin Society in 1899 and 1902, and before the Institution of Electrical Engineers in 1902.

From about 1902, the investigations were carried out in the laboratories of Hadfields, Ltd., in Sheffield.

In the discussion in 1905 on the Seventh Report of the Alloys Research Committee of the Institution of Mechanical Engineers, "On the Properties of a Series of Iron-Nickel-Manganese-Carbon Alloys," Barrett, referring to the foregoing investigations, said "It was now a good many years ago since his friend, Hadfield, asked him to co-operate with him in testing the physical qualities of that remarkable series of alloys of iron which Hadfield prepared with such skill and cost. The mechanical tests and the chemical analyses of these alloys were made by Hadfield at the Hecla Works, but the determination of the magnetic and electrical properties were made by himself (Barrett) in co-operation with Brown." He was also kind enough to say that "he desired to express the great obligation science was under to Hadfield for preparing these various alloys, setting an example to English manufacturers, the true scientific spirit which, he hoped, would be more and more widely diffused throughout the great manufacturing works in this country."

As often happens, however, the results from small specimens in a physical laboratory could not be obtained when working on a large scale without further investigation.

In this connection a scientist in America, Dr. Hayes, in an article which appeared in the "Iron Age" of July 10th, 1924, with regard to recent researches on the production of malleable cast-iron in a few hours, as compared with ordinary methods, stated "It must not be forgotten that laboratory experiments and demonstrations by the scientist, whilst highly valuable, often do not take sufficiently into account the difference between them and actual working conditions. For example, in the case just mentioned, the sudden and accurately controlled changes of temperature easily produced in the laboratory on a few pounds of material cannot be commercially reproduced upon tons, amongst other reasons being the high heat capacity of larger masses, and the greater chance of non-uniformity of temperature under such conditions. The individual, even if guided or inspired by laboratory practice, has often to completely modify his methods to make them useful for practical application. This is where inventive capacity comes in, that is, in the combination of theory and practice. The scientist may discover certain facts, but these are of little value until

the combination of practical knowledge and application is effected."

In the case of the author's iron-silicon alloys, similar alloys possessing the same satisfactory electrical and magnetic qualities as shown in the tests referred to could not be reproduced on a large or manufacturing scale until many difficulties had been overcome.

In the present case, small laboratory tests, whether as regards the experimental steels themselves or the tests obtained therefrom, whilst most useful and of the highest importance as pointing the way, were insufficient as regards practical application.

The successful production of the silicon steel on a manufacturing scale was surrounded with difficulties, all of which had to be surmounted. The casting qualities of the alloy were quite different from those of ordinary steel; the shrinkage and piping were unusually great and most difficult to deal with; all kinds of special means had to be provided to overcome these troubles. Then the material was, at first, most intractable as regards forging and rolling in the larger masses required, as compared with the small specimens prepared for the laboratory experiments. Very often the ingots on being put into the rolls or under the press or forge hammer, split or cracked, and the sheets produced therefrom were unfit for use. Some of the ingots did not even reach this stage but broke into dozens of pieces. The waste of material was thus at first frightfully heavy, in fact, there was more steel wasted than was usable.

It may be mentioned that during the early stages of the production of this material the author's firm, being steel founders, devoted their attention chiefly to the production of castings, and did not at that time possess rolling mills or heavy forges for manufacturing bars or sheets, so that with the plant they possessed they could only supply the steel in ingot form, or forged at considerable cost into slabs, the material being afterwards finished into sheets, annealed, and dealt with by Messrs. Joseph Sankey & Sons, who finally took over the complete manufacture of this material, under the well-known name which they applied to it, of "Stalloy." At a later stage, Messrs. Lysaght also undertook the manufacture.

The correct method of heat treatment and manipulation of the ingot and of the billets, blooms and slabs, from which the sheets were finally obtained, had to be most carefully

studied, and the material in the final form of sheets required very special annealing or heat treatment methods.

Again, the composition of the alloy first thought to be suitable, was found to require considerable modification in order to obtain the results desired by the electrical engineer. A material with half-way qualities was not wanted. The watt losses per lb. ordinarily obtained were about 1·25, in fact, anything under about 2·10 was acceptable. To-day, however, watt losses of even 0·50 per lb. are demanded. These figures refer to a frequency of 50 cycles per second, and an induction density of 10,000 lines per square centimetre.

It was found that for silicon steel of the best quality to be produced, it must, in its final form, be practically an alloy of iron 95·00 to 96·00 per cent., and not less in silicon than 3·50 to 4·00 per cent., with the carbon, sulphur, phosphorus, and manganese as nearly as possible absent, a composition of alloy steel most difficult to produce. To meet the severe demands of the electrical engineer these four elements should not exceed about 0·25 per cent. In fact, such alloys as those originally produced would not meet the present-day requirements and would be rejected by electrical engineers. The omission of the addition of manganese to the silicon steel appeared to make the material quite red-short until the necessary various heat treatments, whether as regards dealing with the ingots, billets or slabs, or the finished product, were worked out, thoroughly understood and brought under control by means of the various scientific aids which were really not available in a practical way when the material was first invented. Furthermore, the type of ferro-silicon or other silicon alloys then available, as used in the manufacture of the steel, was considerably inferior to those produced later.

As already mentioned, there was also the important question of temperature determination to be grappled with. In those earlier days, when pyrometric practice was in its infancy, with all the difficulties attending its application, many obstacles had to be overcome, not only in producing this complex and difficult silicon steel, but also in rendering it subsequently a practical success. Most valuable and useful as were the tests which determined the electrical and magnetic qualities, these were only the commencement of the successful production of silicon steel suitable for electrical purposes. As before stated, the

results of tests on small specimens, could not be repeated in the mass. Manufacturing difficulties with small size ingots were intensified very greatly in the sizes of ingots required industrially, in fact, so much so, that at one time it seemed as if they could not be overcome, and that the production of this promising material would have to be abandoned owing to the excessive waste and high cost of production. As pointed out in Chapter XI, it was not until about 1900 that the means of accurately determining temperatures for practical purposes were perfected and introduced.

In an interesting leading article which appeared in the "Electrician" of November 28th, 1924, there was reviewed the effect of "annealing" upon sheets for transformers, including mild steel as well as silicon steel. Attention was there rightly called to the great variations in quality which comparatively slight differences in heat treatment occasion in the electrical properties of steel employed for transformer stampings and other work. Particulars of a recent research in this direction appeared in the "Revue de Métallurgie" of August, 1924. This research contains valuable information to those interested in the problem. Most of the results showed that annealing carried out at too high temperatures gave quite as bad results as those which were too low. The ratio of time and temperature upon the material being treated were also shown to be of the highest importance.

Metallography of Silicon Steels.—The special characteristics conferred upon iron by the addition of silicon, and the need therefore of modified methods of heat treatment and manipulation, are further exemplified by the following reference to work carried out by the late Dr. J. E. Stead, F.R.S., afterwards President of the Iron and Steel Institute in 1920-1922. In 1898 he read a paper of much interest before that body, on "The Crystalline Structure of Iron and Steel," and showed part of a grain of steel containing $4\frac{1}{2}\%$ of silicon with which the author had supplied him. The actual composition was carbon 0·25%, silicon 4·49%, and manganese 0·36%.

By kind permission of the Iron and Steel Institute, this photomicrograph is reproduced in Plate XXV. Stead termed this the most perfect crystal structure he had ever been able to develop by metallographic methods. He also pointed out that these silicon steels low in carbon were peculiar in the respect that heating up to even 1100°C. effected no structural

change. The granular junctions remained exactly as they were before heating, as was demonstrated by heating forged specimens in which the granules were lenticular in form. Heating did not restore the equi-axed granules as it does the drawn-out granules of ordinary steel and iron.

In the paper in question, Dr. Stead pointed out that the late Professor F. Osmond and Professor Arnold showed that there is no arrest-point or allotropic change at Ar_3 (850°C. to 870°C). in the high silicon steels and aluminium alloys, such as those described in the author's papers to the Iron and Steel Institute in 1889 and 1890. This is coincident with the absence of structural change by heating to above 870°C. As carbon is practically absent there is no arrest at Ar_1. These observations are fully confirmed by heating and cooling curves prepared by the author, see Plate XXX.

Stead stated that even if carbide of iron were present with this high amount of silicon, it could not decompose and absorb the heat necessary to give the arrest Ar_1.

He submitted specimens of the silicon steel mentioned, together with those of ordinary iron and steel, to the cementation process. Although the other samples became highly carburized, the silicon steel did not absorb any carbon. As $4\frac{1}{2}\%$ silicon leaves no iron free to combine with carbon at the temperature of the cementation furnace, this result was to be expected.

Dr. Carl Benedicks, in his thesis for the Doctorate of Upsala, presented an admirable Address entitled " Physical and Physico-Chemical Researches upon Carbon Steel," describing research work carried out during the years 1900 to 1904, chiefly at the Institute of Physics of the University of Upsala. This was published in 1904, and contains many references to silicon steel and the researches of various experimentalists. A large number of photomicrographs of specially high quality accompany the thesis, which is a model to all those engaged in research work.

Difficulties of Introduction.—These various foregoing facts are mentioned in order to indicate not only the great and many difficulties which had to be surmounted before success could be achieved, but also to show why so many years were involved before the silicon steels which the author made in 1883–1884, especially that type with low carbon and high silicon, became industrially and commercially possible.

PHOTOMICROGRAPH OF SILICON STEEL.
COMPOSITION:—0·25 % C, 4·49 % SI.

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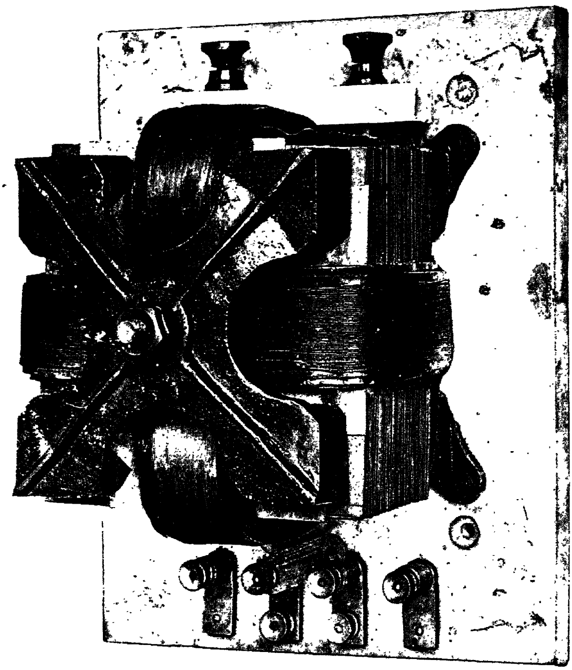
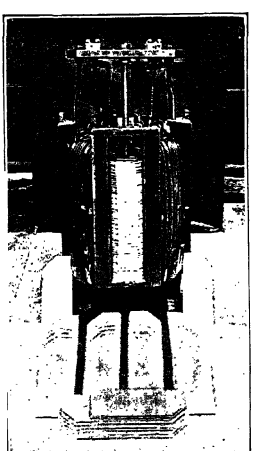
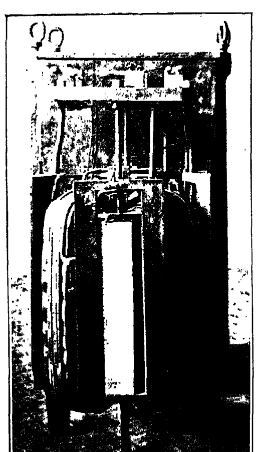


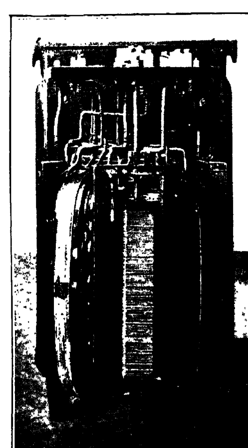
THE ORIGINAL SMALL TRANSFORMER, CONSTRUCTED IN 1903, OF HADFIELD'S SILICON STEEL.



40 K.W. TRANSFORMER, CONSTRUCTED IN 1905.



60 K.W. TRANSFORMER, CONSTRUCTED IN 1906.



40 K.W. TRANSFORMER, OF BEST TRANSFORMER IRON.

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No wonder that many of those concerned in the early work from time to time thought the material was a myth or a mare's nest. Also, intending users could not understand why they could not obtain the requisite material with its valuable qualities. However, the facts now given show the reason why. A similar course of events occurred more or less with the introduction of manganese steel. So it is generally the case with all inventions of complex nature, such as these are. The general public and outsiders imagine that inventions mean perfection at once, but it is not so. With few exceptions, they are only the commencement of a long travelling on the hard high road of bitter experience, the difficulties of which can only be overcome by much work and perseverance.

Another difficulty was that the user would not entertain the question of adopting the silicon steel because he claimed the cost was too high. He could not understand that the mere addition, as he considered it, of a few per cent. of a comparatively cheap element like silicon, obtained with ferro-silicon made in the blast or other furnace, should add so seriously to the cost, which, until the material came to be called for on a large scale, was necessarily very high, owing to the great amount of waste material in its production. Another point, too, should be mentioned, namely, that to use the new silicon steel to the best advantage, meant a complete revolution in the design and construction of electrical apparatus, such as transformers, in which it was chiefly to be used.

All this took time, in fact lots of it! It was not until 1906, that is, seven years after the first papers were read announcing the discovery, that a single ton of the material was sold by the author's firm, and still later before its production became possible on a manufacturing scale.

As regards the first application it was with much difficulty that a small quantity of sheets was prepared sufficient to build the small transformer shown in Plate XXVI. This, judged by contemporary standards, gave satisfactory results, although the composition of the sheets and their quality were not such as would meet the present-day requirements of electrical engineers. Nevertheless, this small transformer gave the first evidence in a practical way of the eventual important application of silicon steel to electrical purposes.

The silicon-iron sheets used in the larger transformers shown in Plate XXVI represented an advance as regards treatment

on those used for the small transformer, although they, too, would not compare with the high quality silicon steel eventually produced of the type used in the construction of the larger modern transformer illustrated in Plate XXVII.

It will, therefore, be understood how very heavy were the expenditures of time and money involved in this early stage of development. Large amounts of material produced had, as already mentioned, to be rejected and scrapped. Results on specimens sent out for testing were most contradictory; sometimes satisfactory results were obtained, and at other times the material was found to be inferior even to the transformer iron then in use. These anomalies had to be investigated and explained before real advances could be made.

Meanwhile, progress was made in several directions, giving the desired results in better quality material. The composition of the steel and methods of heat treatment were improved, these being covered from time to time by further patents as occasion required. Ingot and rolling-mill difficulties were surmounted, aided considerably by improvement in the general knowledge of pyrometry and its employment, which, in that decade, had fortunately also advanced by leaps and bounds.

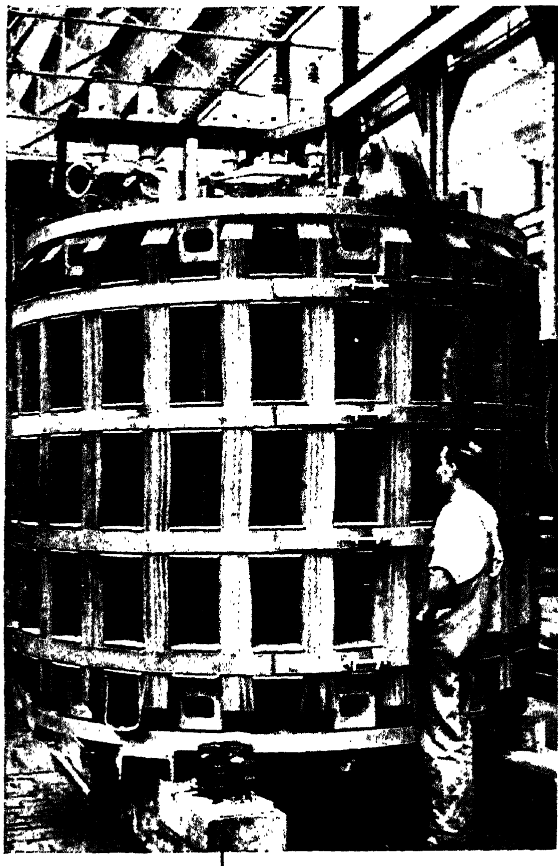
Many prejudices have to be overcome when introducing new alloy steels; no one has found this to be so more than the author. All kinds of objections are raised, some of them inherent to new materials, others demand new types of machines and the scrapping of old types. The maker himself has much to learn and many difficulties to surmount. Fortunately, however, to-day we are not so much hampered by objections of the kind experienced in the days of Charles II, regarding which it is amusing to read that a law was passed that coaches should not be allowed to ply in the streets because of "the destruction caused by their wheels to the paving stones"! The objection most met with when introducing new types of steel is that they are too costly! At first no one will pay the required extra price, so little by little these many difficulties have to be fought and overcome.

As further bearing on the long time required to bring these inventions into successful use, reference may be made to the great work of Faraday in a similar instance. It was in 1821 he discovered the principle of the electric motor, and it was another

LARGE TRANSFORMER OF MODERN TYPE
6000 K.V.A. CAPACITY:

Constructed by the British Electric Transformer Co., Ltd.

THE MAGNETIC CORE OF THIS TRANSFORMER IS MADE FROM SILICON STEEL.



Original small transformer.
0·5 K.V.A. capacity, made in 1903.

THIS LARGE TRANSFORMER, WITHOUT TANK OR OIL, WEIGHS 19 TONS, AND CONTAINS 12½ TONS OF THE SILICON STEEL.

The first transformer made in 1903 from silicon steel is also shown for comparison.

The energy losses due to magnetic hysteresis and eddy currents are only one quarter those which would result from the use of the best iron known prior to the Hadfield invention of silicon steel.

In monetary value this represents an annual saving (with electrical energy at 1d. per unit) of about £3,300; or in three such transformers—representing a set for a three-phase system—nearly £10,000 per annum.

ten years, that is about 1831, before he discovered the equally important principle of magnetic electric induction. Also, as Professor Silvanus P. Thompson once said, "Even the keenest of intellects had not in 1857 grasped the real significance of the dynamo, in fact it was not until 1865-1875 that these principles were made use of practically." This was about half a century after Faraday's discovery in 1821.

Even the greatest of our scientists have not always foreseen and appreciated the important consequences of new discoveries and inventions. For instance, a very famous one, whose name need not be mentioned, said in a letter written at the time of the invention of the telephone: "Yesterday I had an opportunity of seeing the telephone which everyone has been talking about . . . it is certainly a wonderful instrument, though I suppose not likely to come to much practical use." In the same way, having quoted such a bad guess, there should not be omitted an equally good one by the same individual, who in 1908 said: "We may expect to see flying machines in use before many years are past."

Though the telephone soon came into general use for short distance communication, long distance telephony progressed but slowly. Heaviside's principle of improving the range by increasing the inductance of the line, fell on deaf ears for no less than fifteen years.

It is not, therefore, to be wondered at, that in the case of silicon steel, a similar delay occurred.

Although some of the specimens of iron and aluminium alloys dealt with in the joint papers previously mentioned were found, as before stated, to possess remarkable electrical and magnetic qualities, such alloys were not and are not now commercially practicable, both on account of the expensive nature of aluminium, and mainly on account of the great difficulty accompanying the manufacture of such iron alloy due in part to the metal aluminium being so rapidly and readily oxidised.

The history of the successful production of silicon steel has here been given at some length because it is interesting to follow the development of an important invention, and to see how many minds are required to make a successful issue, in the present case those of the metallurgist, the physicist, and the electrical engineer.

Although the author invented and made high silicon steel,

low in carbon, in 1883–1884 it was not until 1906, that is, an interval of no less than twenty-one years, before his firm produced even a ton of this type of silicon steel to be dealt with commercially in this country for use in electrical apparatus.

The electrical engineer, too, was not ready for a new and improved material, as in order to make the best use of it new designs of machines and apparatus had to be prepared, all involving a large expenditure of time and money to carry into effect.

In a like manner, the introduction of manganese steel, invented in 1883, also required many years before this important alloy steel, now used so considerably throughout the world, became industrially possible and employed on a large scale.

Improvements Effected.—In order to indicate, by means of figures, the improvements made in the quality of silicon steel for electrical purposes, by comparison of present-day materials with those previously used, Table IX may be of interest. Part (A) of this table shows the total magnetising losses which include those arising from both hysteresis effects and eddy currents which, for this purpose, are expressed separately in the two units commonly used in this country and in America respectively. In the former, a frequency of alternation of 50 cycles per second is usually adopted, and in America most commonly 60 cycles. Part (B) of the table shows the relative contributions of the effects of magnetic hysteresis and of eddy currents in determining the total losses of the same materials.

In respect of the quite recent work on the magnetic and electrical properties of the ternary alloys, iron, silicon, and carbon, reference should be made to the interesting researches of Mr. T. D. Yensen of the Westinghouse Laboratory. He has been able to obtain alloys with the carbon reduced to a very low order, in some cases down to 0·01%. This results in a considerable decrease of hysteresis loss. His observations led him to believe that the presence of carbon in solution, as distinct from precipitated carbon, was the chief cause of the increasing hysteresis loss, but that the other forms of occurrence of carbon, as in pearlite, cementite, and graphite, had a much smaller effect.

If the effect of dissolved carbon is represented by 100, the effect of carbon as pearlite is 16·50; that of carbon as cementite 2·25; that of carbon as graphite, practically nil.

TABLE IX

ACTUAL AND PERCENTAGE VALUES FOR HYSTERESIS AND EDDY CURRENT LOSSES IN SILICON STEEL COMPARED WITH CHARCOAL IRON AND MILD STEEL.

(A)—Total Hysteresis and Eddy Current Losses.

Total Losses at an Induction B=10,000 CGS.

For Sheets ·014″ in Thickness.

MATERIAL	FREQUENCY 50 cycles per second		FREQUENCY 60 cycles per second	
	Watts per lb.	Watts per kg.	Watts per lb.	Watts per kg.
(a) Charcoal Iron	1·20	2·65	1·54	3·4
(b) Mild Steel	1·09	2·41	1·41	3·1
(c) Silicon Steel of 1903...	0·78	1·73	0·98	2·15
(d) Silicon Steel in 1912...	0·66	1·45	0·82	1·8
(e) Selected Silicon Steel in 1912	0·59	1·30	0·74	1·62
(f) Representative material of good quality of the present-day, containing about 3·50% Silicon... ...	0·58	1·28	0·73	1·60
(g) Silicon Steel of superior quality	0·44	0·97	0·56	1·23

(B)—Percentage of Hysteresis and Eddy Current Losses.

MATERIAL	FREQUENCY 50 cycles per second		FREQUENCY 60 cycles per second	
	Hysteresis %	Eddy Currents %	Hysteresis %	Eddy Currents %
(a) Charcoal Iron	67	33	62	38
(b) Mild Steel	66	34	61	39
(c) Silicon Steel of 1903...	78	22	74	26
(d) Silicon Steel in 1912...	84	16	81	19
(e) Selected Silicon Steel in 1912	82	18	78	22
(f) Representative material of good quality of the present day, containing about 3·50% Silicon... ...	81	19	78	22
(g) Silicon Steel of superior quality	75	25	72	28

The presence of sulphur and manganese was found to affect the magnetic properties deleteriously, though the presence of traces of phosphorus seemed on the whole to improve the material. This effect was known a long time ago, but it also tends to make the material more brittle.

Mr. Yensen considers that the detrimental effect of sulphur, phosphorus and manganese in iron is of the order just mentioned, though phosphorus has a beneficial influence on high silicon alloys. He believes that the intercrystalline amorphous cement in iron can also be regarded as an impurity producing detrimental effects, hence the grain size has a large influence on the magnetic properties. In this paper evidence is also produced to show that the increased hysteresis loss, due to carbon and other impurities, which are precipitated in combination with iron, as also the intercrystalline cement, is caused by the inherent hysteresis loss of these impurities.

Quite recently Professor K. Honda, of the Japanese Research Institute for Iron and Steel, made a radiographic examination of the crystal structure of a specimen of the author's silicon steel. The specimen tested was of the same composition as that used in the determination of the heating and cooling curves shown in Plate XXX, namely :

C	Si	S	P	Mn	Al	
·015	3·53	·008	·015	·03	·011	per cent.

The photograms indicate a crystalline structure indistinguishable from that of pure iron, as will be seen by reference to figures A and B of Plate XXVIII. In addition, the lattice constant is of closely the same dimensions, namely 2·860 Angstrom units for the silicon steel compared with 2·864 for the specimen of pure iron.

It is evident, therefore, that the remarkable magnetic properties of this silicon steel are not the result of any special crystalline formation or grouping of the atoms, but afford a still further demonstration, if this were required, that magnetic properties probably reside in the individual atoms. In the case of silicon steel, it is still not yet clear in what way the presence of silicon atoms is able to modify so advantageously the magnetic properties of the iron atoms.

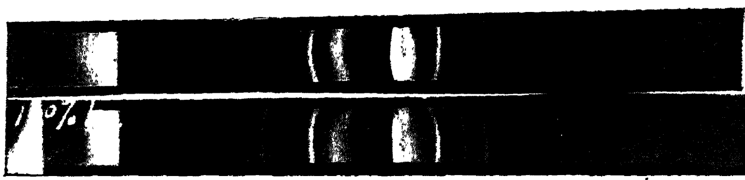
It will thus be seen that many of the difficulties, when introducing silicon steel, were due to points which in those days could not be foreseen because there was not the necessary knowledge or experience, in fact, science itself had

X-RAY SPECTROGRAMS OF SILICON STEEL (3½% Si) and PURE IRON.

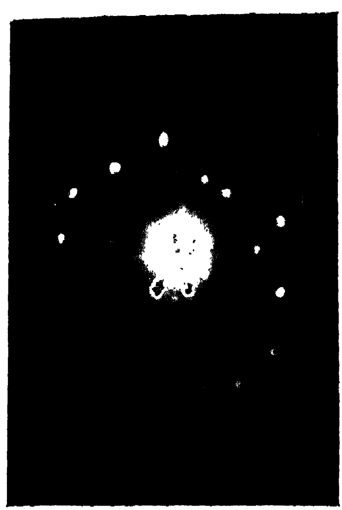
TESTS CARRIED OUT BY PROFESSOR HONDA, OF THE JAPANESE RESEARCH INSTITUTE FOR IRON AND STEEL.

ANALYSIS OF THE SILICON STEEL :—

C	Si	S	P	Mn	Al
·015	3·53	·008	·015	·03	·011



A.—SILICON STEEL. B.—PURE IRON.



C.—LAUE PATTERN, SILICON STEEL.

Figs. A and B indicate that the crystalline structure of Silicon Steel is indistinguishable from that of Pure Iron. In addition, the lattice constant is of closely the same dimensions, namely, 2·860 Angstrom units for the Silicon Steel compared with 2·864 for the specimen of Pure Iron.

It is evident, therefore, that the remarkable magnetic properties of Silicon Steel are not the result of any special crystalline formation, but afford a still further demonstration, if this were required, that magnetic properties reside in the individual atoms. In the case of Silicon Steel, it is still not yet clear in what way the presence of Silicon atoms is able to modify so advantageously the magnetic properties of the iron atoms.

not reached that stage of knowledge in which an explanation could be given for many of the troubles then experienced.

Applications of Electrical Engineering—In speaking of the wide applications of electrical engineering nowadays to everyday life, the following are striking facts: the first central electric lighting station in the United States began operation in New York City on September 4th, 1882. It started with 59 customers, and so sceptical were these users that service was furnished them without charge for five months. In 1924 there were $14\frac{1}{2}$ million customers served by central electric stations.

It will be of interest to give a comparison of the use of electrical energy in the United States and Great Britain as indicated by the kilowatt hours of current generated by central electrical light and power stations and electric railways in 1922. For the United States the total was 45,300,000,000 and for Great Britain 4,880,000,000. These figures at 1d. per unit would amount to a total value of £189,000,000 and £20,300,000 respectively. The consumption of electricity in the United States is on an enormous scale, and it should be remembered the figures just mentioned do not include the output from electrical plants operated by mines, factories and hotels which generate their own energy, nor those operated by the Federal Government and State Institutions. In our own and other countries, the use of electrical energy is rapidly increasing. Probably the grand total value of electric energy now used in the world cannot be far short of £300,000,000 per annum. What a splendid investment this is for the human race in the hundred and one applications of electric energy for modern comfort and convenience, whether as regards lighting, heating, or traction.

Interdependence of the Metallurgist and the Electrical Engineer.—As already stated, without the aid of the metallurgist the electrical engineer could never have reached the high position he has done to-day. This shows how interdependent the various branches of science are. Electrical requirements have called for the development and application of all kinds of special steels, both cast and forged. The following are some of these applications. In steel castings; magnet and other castings up to about 50 tons in weight; armatures, pole-pieces, rotor spiders, dynamo and motor castings; also rotor and other forgings of high permeability steel. There is also the wide application of silicon steel in the form of sheets for transformer and other work.

In order to show the very large savings which the use of silicon steel has brought about, it is interesting to note what has been said by the able head of the Magnetic Research Division of the Westinghouse Laboratory, Mr. T. D. Yensen, who has made many important contributions to this subject of magnetic qualities of metals. In an article to the *Electric Journal,* March, 1921, entitled, "The Development of Magnetic Materials," he refers to silicon steel, stating that "he estimates the total saving already effected to the world by this material in reducing energy losses, saving in copper, better apparatus and other advantages, amounts to no less than 240 million dollars, or about eighty million pounds sterling at the then rate of exchange," and adds the words "nearly enough to build the Panama Canal."

Mr. Yensen's estimate referred to the saving effected down to the end of the year 1920. From the rapid rate of increase in the use of electrical power, as stated by official American records, calculations on a similar basis show that the saving effected at the present time amounts to about 70 million dollars annually, so that down to the end of the year 1924 the total saving effected, since the introduction of silicon steel, amounts to not far short of 700 million dollars, or about 140 million pounds sterling.

The method by which this result has been arrived at has been to take an approximate estimate of the total consumption of electricity for the years 1903 to 1923, taking the estimated savings *pro rata.* The data with regard to the use of electrical energy in the United States as set forth in the "Manufacturers Record" of October 25th, 1923, also other data for earlier years, has enabled an estimate to be prepared with a fair degree of certainty, that is, for the United States; then by doubling these figures exactly as Mr. Yensen did, to cover the whole world.

Other calculations have also made quite independently, as certain American authorities have done, based on what is known would be the iron losses, that is the transformation losses, associated with the supply and use of such quantities of electricity. The figures arrived at are of a similar order. There is, therefore, no exaggeration in the amount of the savings mentioned, namely, that since the introduction of silicon steel, the total savings in energy losses this steel has been able to

effect and bring about, amount to the large sum of about £140,000,000, a marvellous testimonial to the value of alloy steels and their study.

Although magnets of permanent type do not owe their existence to the introduction of alloy steels, quite good magnets having in the past been made from high carbon steel, the use of tungsten steel, and more recently, cobalt steel, have resulted in a considerable improvement both as regards actual strength and permanency. These various applications are specially referred to in Chapter X.

American Experience as to the Value of Research.—In this connection it may be of interest to quote the opinion and views of Mr. E. W. Rice, Jr., Sc.D., Eng.D., M.Am.I.E.E., Honorary Chairman of the Board of Directors of the General Electric Company in the United States, probably the largest electrical organisation in the world, regarding both ferrous and non-ferrous alloys.

Mr. Rice in his interesting paper on " New Fields of Research for Power Development," read before the World Power Conference at the Wembley Exhibition in July, 1924, pointed out the extraordinary influence of introduced elements in alloys, whether ferrous or non-ferrous. For example, he stated that the conductivity of copper was reduced no less than 35% by the addition of only 0·10% of silicon. The weight of this small percentage of silicon in one ton, that is 7,000 cubic inches, of copper is only 36 ounces, and its bulk 28 cubic inches. Thus the depreciation in conductivity resulting from this slight difference in composition is far greater than might have been expected.

In a similar way, the effect of 0·002 per cent. of phosphorus on copper, equivalent to 0·57 cubic inches in a volume of 7,000 cubic inches, reduces the conductivity from 100 to 94 per cent. On the other hand, in the case of the silicon steel described in this chapter, the effect resulting from quite a large addition of the same element, silicon, of which a minute percentage is found to completely spoil the copper material just mentioned, was, singular to say, quite otherwise, that is, the large percentage of the added element proves most beneficial. The addition of no less than 4·00% silicon, that is, 90 lbs. of this element per ton (in bulk, 1,150 cubic inches) as compared with 2,150 lbs. of iron (7,900 cubic inches bulk), that is, leaving 96% iron, in properly heat treated silicon steel makes the iron more magnetic

for low magnetising forces, than if the material was pure iron, 100 per cent. At the same time the conductivity is reduced from 100 to about 20%, a factor of importance in lowering the ohmic losses due to eddy currents.

In this valuable paper to the World Power Conference, Mr. Rice also made reference to silicon steel under the heading of "Development of Electric Power based upon Research." On account of its general interest and coming from so high an authority, this is given in full. He says: "While passing in review the progress made in supplying electric power for our benefit, of which I have given but the briefest sketch, and to which each one is able to add indefinitely, one may ask 'What has this to do with Research?' The answer, I believe, is that Research is the foundation upon which this marvellous accomplishment has been built—the research of hundreds of able scientists and engineers in all civilised countries. We think at once of Davy, Faraday, Henry, Ampère, Weber, Helmholz, Edison, Swan, Elihu Thomson, Steinmetz—to mention but a few.

No better example of scientific research, systematically and fruitfully followed, can be found than in the work of Faraday, whose accounts in his 'Experimental Researches' will remain a model and a stimulus to scientific endeavour for all time."

Mr. Rice also pointed out that the author had made possible and known the important fact of the existence of silicon steel, and that this steel containing relatively high percentages of silicon, was found of great advantage in reducing hysteresis and eddy current losses. He says "It is quite true that difficult and costly experimental work followed by skilful and refined manufacturing methods were necessary to make this new material available in the quantities and at the costs needed. This development could not have taken place until after the important fact of the existence of such material was made known." It is gratifying to note this reference by Mr. Rice to the value of silicon steel. He further mentioned that to-day silicon steel is obtained for industrial purposes, which gives, with a frequency of 60 cycles per second and 10,000 lines density per square centimetre, a loss of only 0·60 watts per pound, also that with more refined laboratory heat treatment this loss has been brought down to as low as 0·48. Before silicon steel was introduced the loss was at best 1·50 watts per pound, and often from two to three times this amount.

The ordinary steel used also aged rapidly, whereas silicon steel does not do so, in fact its quality is slightly improved with time.

Assistance by the Manufacturers.—It remains for the author to make acknowledgment of the enterprise shown by the manufacturers of the material on both sides of the Atlantic, amongst whom may be mentioned the following: Messrs. Joseph Sankey & Sons, Ltd., and Messrs. John Lysaght, Ltd., both of England, the makers of this "Stalloy" material; and in America, The American Sheet and Tin Plate Company, one of the associated Companies of the United States Steel Corporation; The General Electric Company; and the Westinghouse Company.

CHAPTER IX

HEAT-TREATMENT AND MICRO-STRUCTURE OF STEEL.

It cannot have escaped the notice of the earliest workers in iron and steel that—by modifying the heating to which the metal was subjected to make it forgeable, and by varying the conditions of subsequent cooling—the properties of the product were affected to a very marked extent. Secret processes were handed down from father to son and, though the advance was empirical in nature, the results were good. The smiths of the Middle Ages forged and tempered swords which could hardly be excelled to-day. Nevertheless, there was no scientific knowledge concerning the phenomena associated with heat-treatment of carbon steel until about half a century ago, and it is only since the introduction of alloy steels that the full possibilities and importance of heat-treatment have been realised. Sorby's great and original work in metallography, followed on by the work of Arnold, Stead, Osmond, Sauveur, Guillet, Benedicks and others, opened up a new field of investigation which, combined with the application of the pyrometer, rendered possible the development of exact and methodical heat treatment. The adoption of these methods made the use of the microscope more important than ever, as it was possible actually to see and interpret the character and structure of the various metals experimented upon in their different conditions.

The Importance of Heat-Treatment.—From the earliest days in the history of modern alloy steels it has become increasingly apparent that heat-treatment is at least as important as chemical composition in determining the properties and practical value of steels. To-day it is generally recognised that proper heat-treatment is essential to the development of the best characteristics in most steels with but few exceptions, and the heat-treatment to be adopted for various applications is specified as a matter of course.

The author's discovery that manganese steel was toughened by water-quenching—instead of being hardened, as in the case of carbon steels—afforded a striking proof of the importance of heat-treatment, but it was many years before this question received the full consideration which was its due. For example, in Howe's monumental work on "The Metallurgy of Steel," chromium to the amount of from 0·12 to 0·54 per cent., even in the presence only a moderate percentage of carbon (exceeding 0·3 per cent.), was held to injure the shock-resisting power of the steel. This statement was made at a time when armour-piercing projectiles made by the author's firm, containing three or four times as much carbon and chromium, were penetrating unbroken, hard compound armour plates of a thickness nearly double the calibre of the projectiles. The reason for this apparent contradiction lay mainly in the question of heat-treatment. The points of the projectiles which gave such remarkable results were specially hardened by suitable heat-treatment; without correct heat-treatment the projectiles would simply have splashed against the plate.

The fact that heat-treatment is an essential factor in the preparation of alloy steels for service, and the remarkable results thus obtained, led to an increased appreciation of the possibilities of heat-treatment in connection with carbon steels. The advance in knowledge concerning alloy steels reacted, in fact, upon the technology of carbon steels and led to the discovery that properly treated carbon steels are comparable with the more expensive alloy steels in many applications.

The work of the metallurgist during the past forty years has benefited the engineer by providing not only new alloys, but also methods of heat-treatment which enormously increase the practical value of both alloy steels and simple carbon steels.

In this connection, it would be difficult to over-estimate the importance of the work done by Professor Henri le Chatelier in the development of the whole subject of pyrometry and, in particular by the introduction of thermo-electric and optical pyrometers, referred to in Chapter XI. Accurate means of measuring high temperatures assist materially in the correct heat-treatment of alloy steels, without which the valuable properties of the latter cannot be fully developed. Even where simple carbon steels are concerned, accurately controlled heat-treatment is of far greater importance than is generally recognised.

Recalescence.—To Dr. George Gore, F.R.S., author of that admirable book *The Art of Scientific Discovery* which is mentioned more fully in Chapter XIII, belongs the credit for experiments which led ultimately to the discovery of the property of recalescence and so to the scientific heat-treatment of steel. It was in 1869 Gore discovered that iron wire, when cooling from a high temperature, momentarily elongated at a certain critical temperature between 700° and 800° C. The reverse action, or contraction on heating, was discovered by Sir William Barrett and reported at the British Association Meeting at Bradford, in September, 1873 ; it was also recorded in a paper subsequently published in the *Philosophical Magazine* in December, 1873. He further discovered that, at the critical temperature in question, iron by the action of heat loses its magnetic qualities. In the same paper the phenomenon known as the recalescence of steel, and hard iron wire, was first noted and described. Barrett had observed that when such iron and steel is raised to a white heat and allowed to cool, it obeys the ordinary law of cooling until it reaches a point near obscurity. At this point, a temperature of between 700° C. and 800° C., the temperature suddenly rises, and the wire glows again to a red heat.

Professor Tait, Professor Tomlinson, Mr. Newall, Dr. John Hopkinson, and others gave the subject attention, and in 1889 the British Association formed a Committee, which consisted of Professor Fitzgerald (Chairman), Mr. Newall, and Mr. Trouton, with Sir William Barrett as Secretary, to investigate the phenomenon and its probable causes.

As in the case of many other discoveries, no special use was made of this important fact of recalescence for many years. The work of those mentioned and of the British Association Committee improved knowledge with regard to its actual character and its significance in relation to the internal changes in the iron and steel which produce this outward and visible sign. Its importance in connection with the heat-treatment of steel, however, was not achieved until after the valuable work done by Professor Osmond in France, and Sir William Roberts-Austen in this country, who, by taking graphical pyrometric records of the rates of heating and cooling of iron and steel, were able to associate this evolution of heat and the corresponding absorption on heating with definite physical changes in the material. These further researches received

much assistance from the improvement in methods of determining high temperatures which had resulted to a large extent from the work of that great French scientist, Professor H. le Chatelier.

From this combined research work have developed many remarkable applications to the metallurgy of iron and steel. Other metals, with the exception of nickel and cobalt, show very little change under heating and cooling; and the changes which do occur in these two metals are in no way so pronounced as in iron.

Arrest Points in the Heating and Cooling of Iron and Carbon Steel.—The heat-treatment of steel is closely associated with certain critical changes which occur at more or less definite temperatures on heating and cooling. When pure molten iron is allowed to cool from, say, 1,500° C. it is found that the temperature falls steadily to about 900° C., but at this point the cooling is greatly retarded until a temperature about 880° C. is reached; this retardation, which corresponds to certain internal changes in the iron, is known as the A_3 change point. From about 880° C. cooling proceeds regularly down to about 770° C. where another distinct but less pronounced retardation occurs, known as the A_2 change point. In carbon steels there is another retardation in the rate of cooling at about 700° C., known as the A_1 change point or the point of recalescence. At this point, the heat evolved by internal changes in the constitution of the steel may not merely compensate for the radiation of heat from the metal, so that the temperature remains constant for a time, but may actually cause a temporary rise in temperature.

Above the A_3 change point the iron is in the "gamma" condition which differs in many respects, but chiefly in its crystalline formation, from the "alpha" condition assumed by the metal when it cools below this critical temperature. The A_2 change point is associated with the magnetic properties of the iron; above this temperature the metal is practically non-magnetic, but immediately below the A_2 point iron becomes highly magnetic and remains so at all lower temperatures. The A_1 change point is associated with the carbon in steel, for at this point the carbon, which was in solution at higher temperatures, is precipitated as thin laminae of cementite (carbide of iron) alternating with laminae of iron, the resultant structure being known as "pearlite" from its pearly appearance

when viewed under the microscope; see photomicro. No. 7, Plate XXXIV.

In carbon steel, the temperature at which the A_3 change occurs, falls as the percentage of carbon increases. With 0·5 per cent. of carbon in the steel the A_3 and A_2 points are coincident at about 770° C. With higher percentages of carbon the A_3 and A_2 points remain together, but occur at a lower temperature as the amount of carbon rises till, with 0·9 per cent. of carbon the A_3, A_2, and A_1 changes occur simultaneously at about 700° C. Owing to a certain lag, the arrest points occur at lower temperatures on cooling than on heating and, in order to distinguish between them, the critical points during heating are denoted by Ac_1, Ac_2, and Ac_3, the corresponding arrest points during cooling being denoted by Ar_1, Ar_2, and Ar_3.

Broadly speaking, it is believed that the hardening of carbon steel is effected by heating the metal above the Ac_1 point, so that the carbon may enter into solution in the iron, and then quenching it, so that there is no time for the carbon to come out of solution as the metal cools. Conversely, annealing consists in heating the steel above the Ac_1 point and allowing it to cool very slowly so that the metal is relieved of internal strains, softened, and converted to a fine-grained structure. By re-heating hardened carbon steel to various temperatures below the Ac_1 point different degrees of residual hardness can be obtained, ranging from the maximum hardness of which the steel is capable down to the softness obtained by annealing. The maximum hardness obtainable in the steel depends upon the percentage of carbon present; full glass-scratching hardness cannot be obtained with less than about 0·5 per cent. of carbon in the steel.

Heating and Cooling Curves.—The curves in Plate XXIX refer to a specimen of Swedish charcoal iron and show retardations in the rate of heating at the point A_2 about 770° C., where the magnetic properties disappear on heating and reappear on cooling. Retardations are also shown at the point A_3 in the neighbourhood of 900° C., but, as this iron is practically free from carbon, there is no appreciable arrest at the A_1 point, about 700° C.

As already mentioned in Chapter VIII, there is no structural change in high silicon steels, such as are used for electrical purposes, on heating above 870° C., hence no A_3 change points

T 2657 c

HEATING AND COOLING CURVES OF SWEDISH CHARCOAL IRON.

SPECIMEN No. 2576.

ANALYSIS:-	C.	Si.	S.	P.	Mn.	Fe.
	0·03	0·01	0·013	0·014	0·09	99·84

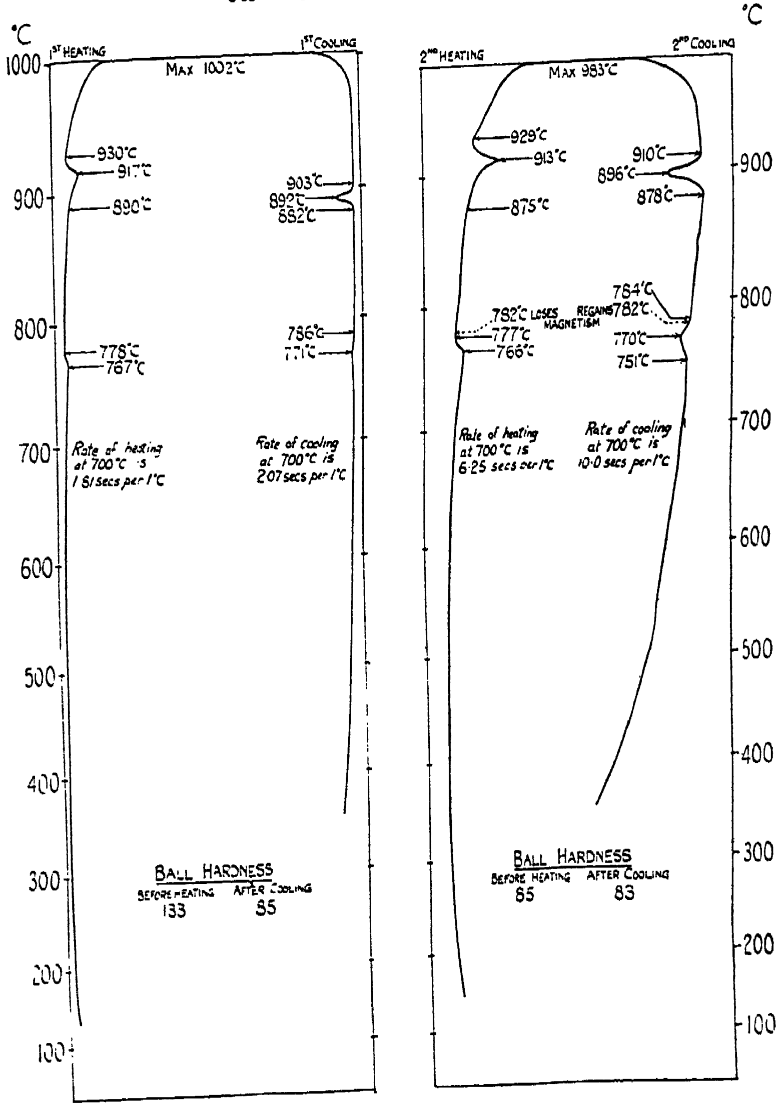
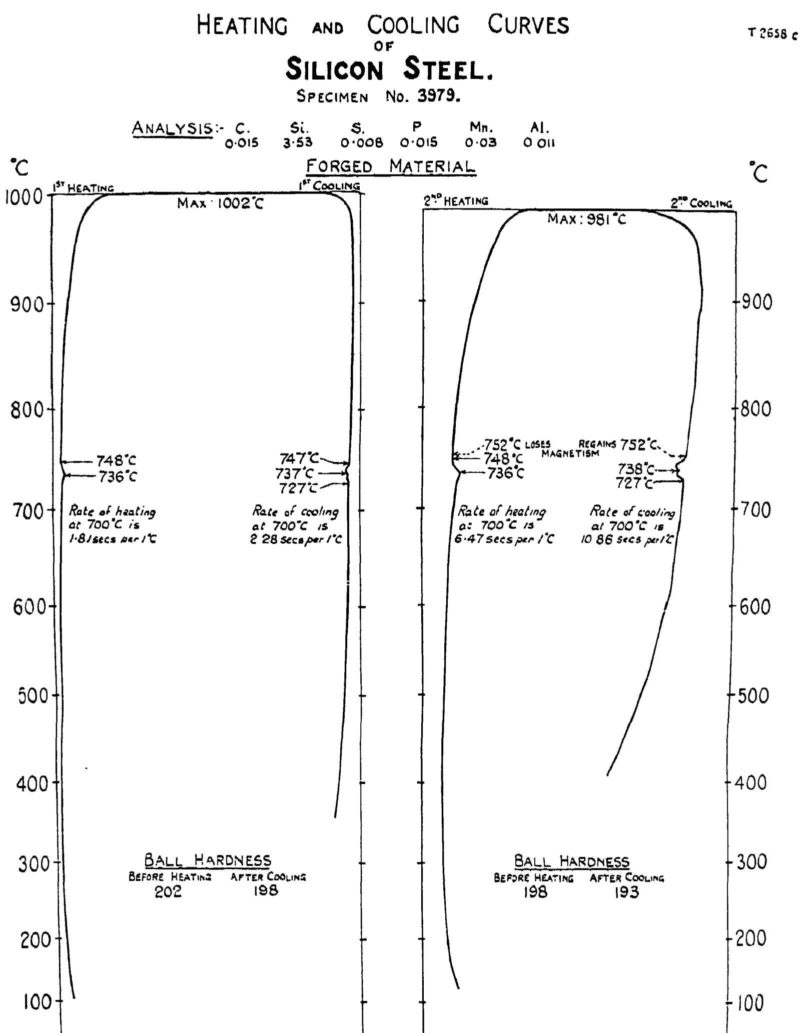
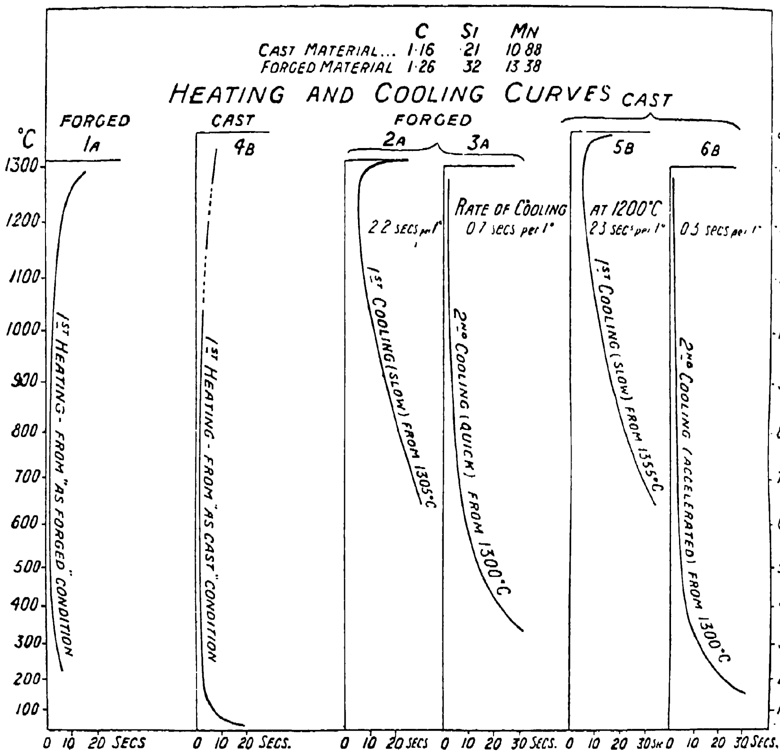


PLATE XXX


HEATING AND COOLING CURVES
OF
SILICON STEEL.
SPECIMEN No. 3979.
T 2658 c
ANALYSIS:- C. 0·015 Si. 3·53 S. 0·008 P 0·015 Mn. 0·03 Al. 0 011
FORGED MATERIAL
°C
1ST HEATING
1ST COOLING
MAX · 1002 °C
748 °C
736 °C
747 °C
737 °C
727 °C
Rate of heating at 700 °C is 1·81 secs per 1 °C
Rate of cooling at 700 °C is 2 28 secs per 1 °C
BALL HARDNESS
BEFORE HEATING 202
AFTER COOLING 198
2ND HEATING
2ND COOLING
MAX : 981 °C
752 °C LOSES MAGNETISM REGAINS 752 °C
748 °C
736 °C
738 °C
727 °C
Rate of heating at 700 °C is 6·47 secs per 1 °C
Rate of cooling at 700 °C is 10 86 secs per 1 °C
BALL HARDNESS
BEFORE HEATING 198
AFTER COOLING 193
1000
900
800
700
600
500
400
300
200
100



HEATING AND COOLING CURVES OF MANGANESE STEEL.

TABLE OF FIGURES.

No.		
1A.	Heating curve	Forged material.
2A.	Cooling curve (slow)	Forged material.
3A.	Cooling curve (quick)	Forged material.
4B.	Heating curve	Cast material.
5B.	Cooling curve (slow)	Cast material.
6B.	Cooling curve (accelerated)	Cast material.

are to be found in the heating and cooling curves for this alloy steel, see Plate XXX. The magnetic change A_2 is still indicated on the heating and cooling curves, though at a rather lower temperature than for Swedish charcoal iron. As carbon is practically absent there is no A_1 arrest.

The fact that quenching and annealing produce, in manganese steels, effects opposite to those obtained in most other steels has already been noted in Chapter VII where, also, test data and photomicrographs are given showing the effects of heat-treatment on this alloy. Another point of distinction from most other steels is that manganese steel shows no recalescence when either being heated up or cooled down in the ordinary way, that is, without quenching. Whereas quenching is required to suppress the critical points in the cooling curve of high carbon steel, there are no critical points in the heating and cooling curves of manganese steel whether the alloy be heated and cooled slowly or quickly.

In order to ascertain whether this alloy steel would show any critical change point when heated to higher temperatures than usual, the author carried out a number of experiments which are fully set forth in his paper entitled "Heating and Cooling Curves of Manganese Steel," read before the Iron and Steel Institute in 1913. By kind permission of the Institute, the various diagrams presented in that paper are reproduced in Plate XXXI.

It will be seen that the curves for both cast and forged specimens of manganese steel show no critical points of any kind, either upon heating or cooling from ordinary, high or even the highest temperatures, up to 1,355° C. There is a slight critical point noticed during the reheating of manganese steel which has been made magnetic by long soaking at about 450° C. to 500° C. In this case the retardation in rate of heating commences at about 630° C.

As mentioned in the paper cited, the critical points in the heating and cooling curves of all ordinary, as well as hardening or self-hardening steels, are of considerable importance in guiding heat-treatment; but where manganese steel is concerned the heating and cooling curves are apparently of no value in this respect, and give no indication of the remarkable alteration of properties which takes place in this material when it is transformed from its original and brittle state into that condition in which it possesses an extraordinary combination

of high tenacity and ductility not equalled by any other alloy of iron or steel.

Micro-structure.—From the preceding notes on the hardening of carbon steels and the different physical conditions of manganese steels before and after heat-treatment, it will be realised that it is possible for steels of the same chemical composition to differ widely in physical properties. Ordinary chemical analysis does not reveal the heat-treatment to which a steel has been subjected and is therefore no guide to the actual structure and mechanical properties of the metal, though it may enable the metallurgist to predict, on the basis of previous experience, the mechanical properties which can be developed by suitable heat-treatment.

On the other hand, microscopic examination of a ground, polished and etched section of the metal enables the experienced worker to arrive at surprisingly accurate conclusions regarding the heat-treatment to which the steel has been subjected, its present mechanical properties, and even in some cases its composition.

To illustrate some of the many features of the microstructure of steel, a selection of photomicrographs obtained in the course of investigations in the Hadfield Research Laboratory is reproduced in Plates XXXII to XXXVII.

Photomicrographs of Iron and Carbon Steels. Nearly pure iron, with not more than 0·03 per cent. of carbon, consists of relatively large interlocking crystals of ferrite which can easily be scratched with a needle. Photograph No. 1, Plate XXXIII, shows the ferrite in wrought-iron, with inclusions of slag elongated by hammering.

The micro-structure of cast-iron, No. 2, Plate XXXII, consists of black rods of graphite on a ground mass of pearlite. The latter consists of alternate laminae of cementite and ferrite, as can be seen clearly on the high-magnification photographs Nos. 2A and 2B, Plate XXXII.

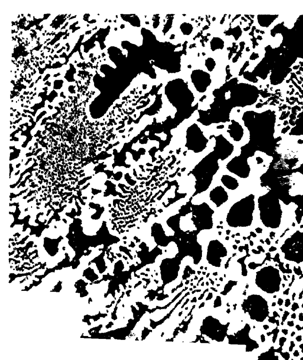
The photomicrograph of white iron, No. 3, Plate XXXII, shows the structures to consist of the eutectic, sometimes called Ledeburite, of cementite (Fe_3C) and pearlite. In this photograph cementite appears white and pearlite black.

Annealed mild steel, containing 0·15 per cent. of carbon, exhibits under the microscope a structure made up of grains of ferrite with small grains of pearlite, black in No. 4, Plate XXXIII, at various places in the grain junctions of the ferrite.

No. 2. ×50.
GRAPHITE AND PEARLITE
CAST IRON.

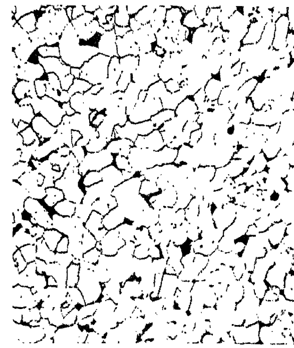
No. 2A. ×1500.
GRAPHITE AND LAMELLAR PEARLITE
CAST IRON.

No. 2B. ×5000.
GRAPHITE AND LAMELLAR PEARLITE
CAST IRON.



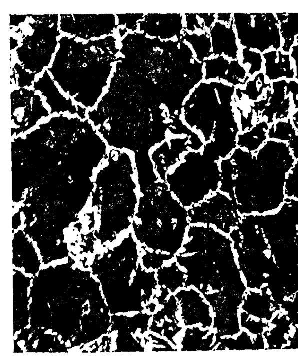
No. 3. ×100.
EUTECTIC OF CEMENTITE AND PEARLITE
WHITE IRON.

No. 1. ×50.
FERRITE AND SLAG
WROUGHT IRON.



No. 4. ×50.
FERRITE AND PEARLITE
MILD STEEL ANNEALED.

No. 5. ×50.
FERRITE AND PEARLITE
MEDIUM CARBON STEEL AS CAST.



No. 6. ×50.
FERRITE NETWORK AND PEARLITE
MEDIUM CARBON STEEL ANNEALED.

Medium carbon steel, with 0·5 per cent. of carbon, when examined "as cast," is found to have an angular type of structure known as the Widmanstatten structure, No. 5, Plate XXXIII. This structure is characteristic of all cast steels containing a medium percentage of carbon. When annealed, medium carbon steel has a cellular structure as shown by photomicrograph No. 6, Plate XXXIII, the ground mass of pearlite being subdivided by cell walls of ferrite. On comparing micrograph No. 6 with No. 5 the effect of annealing, in breaking down the angular and brittle structure of the steel "as cast," is very evident. Photomicrograph No. 6 was taken at a magnification of 50 diameters; on increasing the magnification to 1,500 diameters the appearance is as reproduced in No. 7, Plate XXXIV, the laminated structure of the pearlite—alternate plates of ferrite and cementite—being now clearly visible.

The effect of quenching medium carbon steel is shown by photomicro. No. 8, Plate XXXIV, which refers to the same steel as No. 6, but quenched in water from 900° C., a temperature well above the Ac_3 point. This treatment has resulted in the formation of an acicular martensitic structure. If the steel thus quenched be subsequently tempered at 550° C., the structure becomes as shown in No. 9, Plate XXXIV. This troostomartensitic structure is acicular in form, but its details are masked to some extent by the deposit of carbon produced during the etching of the specimen.

In the micro-structure of annealed eutectoid composition, that is with carbon steel, 0·9 per cent. of carbon, as shown by No. 10, Plate XXXIV, pearlite is the only constituent present. Super-saturated or hyper-eutectoid steel, containing 1·15 per cent. of carbon, has the micro-structure shown in No. 11, Plate XXXV, consisting of a ground mass of pearlite, on which is outlined a thin cellular structure composed of excess cementite, i.e., carbide of iron.

Photomicrographs of Alloy Steels. Turning now to the micro-structure of alloy steels it is impossible, in the space here available, to do more than present a selection from the many thousands of photographs prepared in the Hadfield Research Laboratory.

In this respect the author cannot speak too highly of the many years of important and patient work carried out by the Chief Chemist, Mr. T. G. Elliot, F.I.C., in the Hadfield Laboratory. The joint paper read by the author and Mr.

Elliot before the Faraday Society in the Symposium held in 1920, entitled "Photomicrographs of Steel and Iron Sections at High Magnification," was one of the first to draw attention to the importance of studying high-power magnifications in metallography. In this paper reference was made to, and photomicrographs shown of various kinds of steel examined under magnifications of 5,000 and 8,000.

More recently, the able American metallographist, Mr. Francis F. Lucas, has followed up this line of investigation and submitted contributions with regard to this important subject. In April of this year Mr. Lucas read a paper entitled "Some Recent Developments in Metallurgical Research—New Facts developed by High Power Metallography" before the Conference held at Sheffield by the Royal Microscopical Society.

The structure of manganese steel "as cast" is shown by photomicro. No. 12, Plate XXXVI; in this structure grains of austenite are outlined by free carbide. When this steel has been water-quenched from 1,000° C. the structure consists of pure austenite grains, see No. 13, Plate XXXVI, in which twinning is evident at several places. The microstructure of a specimen of strained manganese steel, prepared from a pulled tensile test-piece, is reproduced in No. 14, Plate XXXVI; the austenite grains, strained by cold work, are covered with what Howe has termed "manganese steel lines." Another interesting photomicrograph is No. 15, Plate XXXVI, which is from manganese steel water-quenched from 1,000° C., then re-heated to 500° C., and maintained at this temperature for sixty hours; the structure is a mixed one consisting of a ground mass of austenitic and martensitic character, with spines of carbide and grains of sorbitic pearlite.

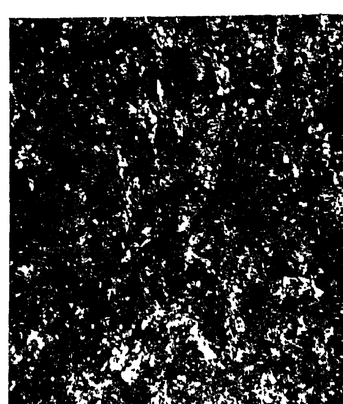
Photomicrograph No. 16, Plate XXXV, is of nickel chromium steel, oil-quenched from 830° C. and tempered by heating to 550° C., followed by quenching in water; this is a typical structure of a low percentage commercial nickel-chromium steel after heating above the Ac_3 point and tempering in water. The acicular structure shown is described as troosto-martensite.

The structure of annealed $3\frac{1}{2}$ per cent. nickel steel consists of a ground mass of pearlite, seen black in No. 17, Plate XXXV, on which a cellular structure is outlined by ferrite (white). When steel of this composition is water-quenched from 800° C. and tempered at 560° C. in water, the structure produced is fine troosto-martensite as shown in No. 18, Plate XXXV.

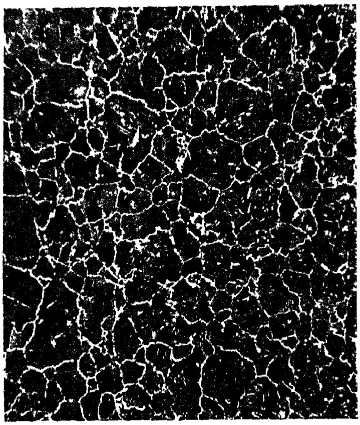
No. 7. ×1500.
LAMELLAR PEARLITE AND FERRITE
MEDIUM CARBON STEEL ANNEALED.

No. 8. ×600.
MARTENSITIC STRUCTURE
MEDIUM CARBON STEEL.
WATER QUENCHED FROM 900° C.

No. 9. × 600.
TROOSTO-MARTENSITIC STRUCTURE
MEDIUM CARBON STEEL
WATER QUENCHED FROM 900° C. AND TEMPERED
AT 550° C.

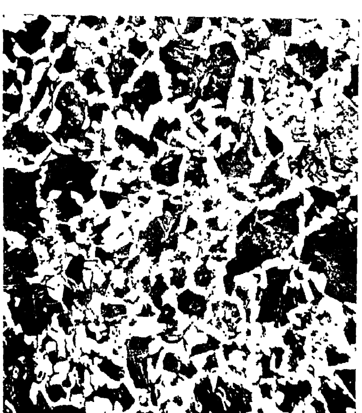


No. 10. ×50.
PEARLITE
9 % CARBON STEEL ANNEALED.

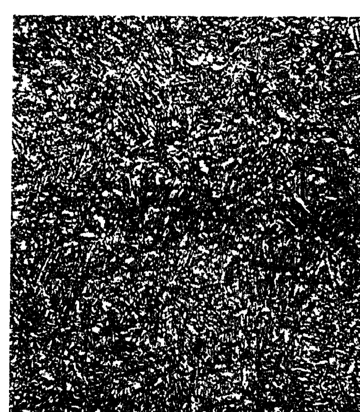


No. 11. ×50.
CEMENTITE NETWORK AND PEARLITE
1·15 % CARBON STEEL ANNEALED.

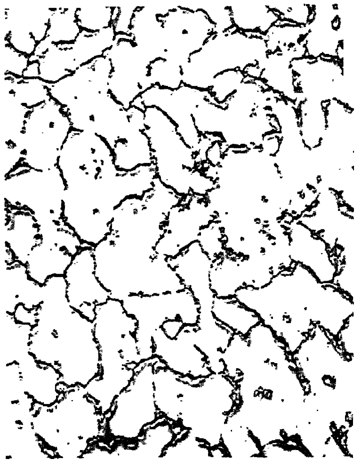
No. 16. ×600.
TROOSTO-MARTENSITIC STRUCTURE
NICKEL CHROMIUM STEEL
OIL QUENCHED AND TEMPERED.



No. 17. ×100.
CELLULAR FERRITE AND PEARLITE
3½ % NICKEL STEEL ANNEALED.



No. 18. ×300.
TROOSTO-MARTENSITIC STRUCTURE
3½ % NICKEL STEEL
WATER QUENCHED AND TEMPERED.



No. 12. ×50.

CARBIDE NETWORK AND AUSTENITE
MANGANESE STEEL
AS CAST.

No. 13. ×50.

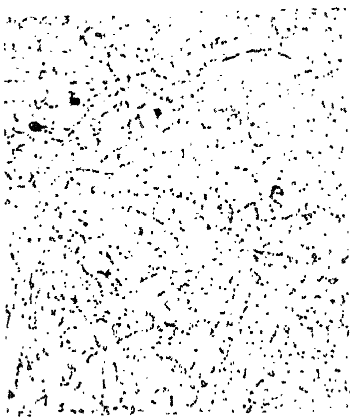
AUSTENITE
MANGANESE STEEL
WATER QUENCHED FROM 1000° C.

No. 14. ×600.

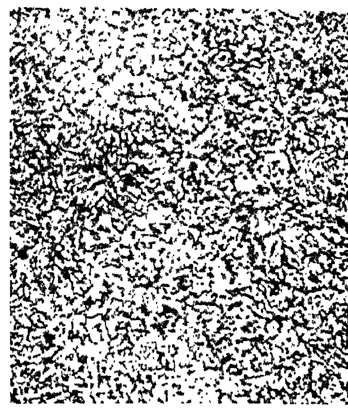
DISTORTED AUSTENITE GRAINS
MANGANESE STEEL
COLD WORKED.

No. 15. ×600.

ACICULAR STRUCTURE
MANGANESE STEEL
WATER QUENCHED FROM 1000° C. AND
RE-HEATED FOR 60 HOURS AT 500° C.



No. 19. ×600.
CHROMIFEROUS FERRITE AND FREE CARBIDE
LOW CARBON, 14 %, CHROMIUM STEEL
(Rustless Iron), ANNEALED.



No. 20. ×600.
CHROMIFEROUS FERRITE AND CARBIDE
13·5 % CHROMIUM STEEL (Rustless Steel),
ANNEALED.

No. 21. ×600.
CHROMIFEROUS FERRITE AND CARBIDE
13·5 % CHROMIUM STEEL (Rustless Steel),
WATER QUENCHED FROM (1) 920° C. (2) 450° C.

The so-called " rustless iron," really a low-carbon 14 per cent. chromium steel, has in its annealed state the micro-structure reproduced in No. 19, Plate XXXVII ; the small globules here visible are of chromium carbide (Cr_3C_2) on a ground mass of chromiferous ferrite.

Photomicrograph No. 20, Plate XXXVII, of annealed rustless steel, with 0·35 per cent. of carbon and 13·5 per cent.of chromium, shows a white ground mass of chromiferous ferrite as in No. 19 ; the dark constituent in No. 20 is carbide, precipitated from the solid solution by the annealing treatment. Rustless steel of this type is, however, generally used in a quenched and tempered condition, and No. 21, Plate XXXVII, exhibits the structure produced by water-quenching at 920° C. and water-tempering at 450° C. This is similar to that shown in No. 20 except that there is now less free carbide present.

Though many more examples might be given, but for the limitations of space, it will be appreciated from what has been said that the nature and disposition of the constituents in the micro-structure of steel afford a most useful guide to the composition, condition, and mechanical properties of the metal. The great work accomplished by Sorby when, in 1885, he showed that the " pearly constituent " of steel was an aggregate of parallel plates, has culminated in the appreciation of microscopy as one of the most valuable means of investigating and predicting the properties of metals.

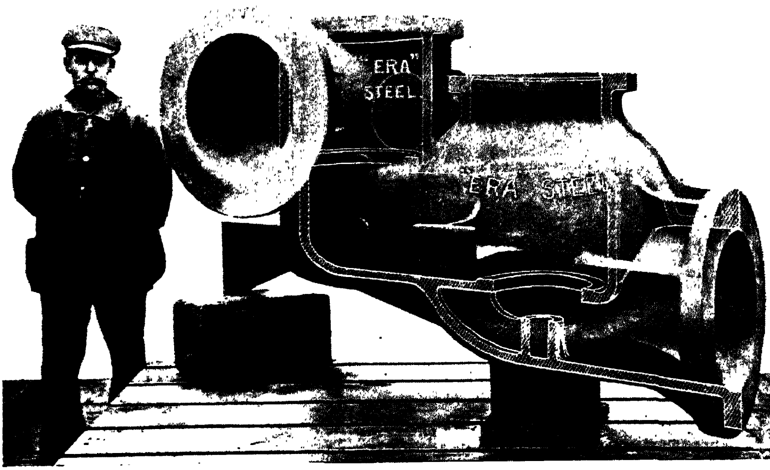
CHAPTER X

APPLICATIONS OF SPECIAL STEELS.

For the purposes of the present chapter the interpretation of the term " special steels " may be broadened somewhat, to include any steel which is given special physical properties whether by alloying with other metals, such as manganese, chromium, nickel, and tungsten, or by special treatment in casting, forging, and heat-treatment with little or no addition of special elements other than carbon. Manganese steel and silicon steel having already been dealt with fully in Chapters VII and VIII, these materials need not be further discussed.

During the past forty years or so, more than 3,000 different steels have been made and tested under the author's supervision, and careful records of their properties and behaviour have been preserved. In proceeding to review, on the basis of this work, the extent and variety of the different applications which have been found for special steels in modern industry and for domestic purposes, either of two methods might be adopted. The first would be to classify the steels according to the nature of the alloying element or elements, indicating the physical and chemical characteristics thus conferred, and the practical applications to which these characteristics give rise. Such a method of treatment would require more space than can here be spared. Moreover, many of those using steel are more interested from the user's point of view than from that of the manufacturer. It will therefore, no doubt, be better to take the various fields of utility for steel and indicate the extent of the invasion of special steels in each direction. In doing this, something may be added to the information given in the author's paper on " The Development of Alloy Steels," read before the Empire Mining and Metallurgical Congress at Wembley in 1924.

Castings and Forgings.—Apart from the work done by the metallurgist in providing new materials, the demands made on him by progress in engineering also require special efforts on his part in the improvement of manufacturing processes,



STEAM VALVE BOX CASTING, WEIGHING 26 CWTS., BEFORE AND AFTER ATTACK BY AN ARMOUR-PIERCING PROJECTILE.

specially in the direction of providing larger and still larger castings and forgings commensurate with the greatly increased size and rating of machinery. This, for the steelmaker, is not simply a question of increasing the scale of his plant. With the increase in size of castings and forgings, metallurgical difficulties arise and have to be overcome. It is relatively a much simpler matter to produce twenty castings or forgings of 1 ton in weight than one of 20 tons—that is, with the same assurance of complete soundness and homogeneity. Such problems have required a great deal of investigation, which, it may be said, has met with the requisite success; the steelmaker is thus able to meet present requirements fully.

The author's father was, in the year 1869, practically the first to take up the manufacture of steel castings on a large scale. He had very considerable difficulty not only in overcoming the technical difficulties of the successful production and application of steel castings, but also in contending with very strong conservatism, even prejudice, against their employment. His enterprise has since been fully justified by the great use which is now made of steel castings.

In an article in "The Machinery Market," dated May 1st, 1884, with regard to the manufacture and utilisation of steel castings produced by the Hadfield firm, it is interesting to note that the following prediction was made:

> "What we have said will, we trust, however, not only be sufficient to indicate in a general way the variety of steel castings manufactured (1884) by the Hadfield Company, but also to illustrate the advantage which cast-steel possesses over cast-iron for most mechanical and constructive purposes for which the latter metal is now chiefly employed. We say, "now chiefly" but the day when cast-iron will yield almost entirely to its more formidable, durable, lighter and stronger rival is not far off. This change will not be the least striking feature of the era of steel into which metallurgical epoch we may now be fairly said to have entered."

Whilst it is true that cast-iron has not been ousted and has still many uses, the extraordinary extent to which steel castings are now employed in this country, the United states, and on the Continent, is most remarkable. In America alone no less than two million tons of steel castings are being used per annum. Although our requirements in this country are not so extensive, there is a large demand here for this useful product.

In the successful production of steel castings, foundry technique is of the highest importance to ensure perfect soundness.

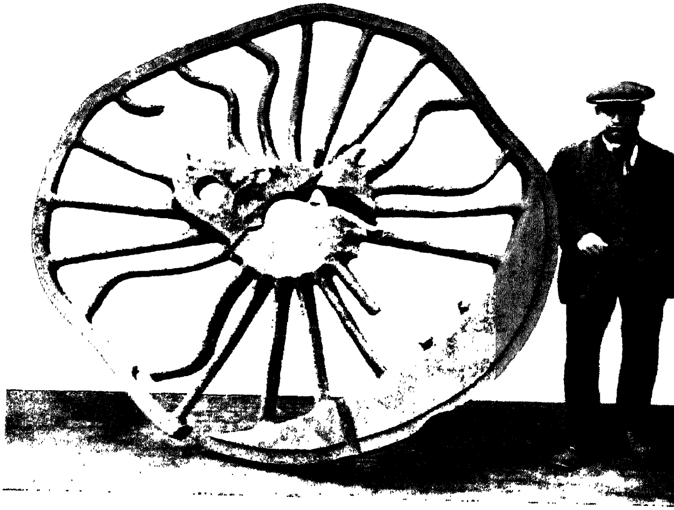
The illustrations on Plates XVIII to XLII, show what can be effected in the way of quality and size by the use of modern methods and equipment.

The steam valve box casting shown on Plate XXXVIII weighs 26 cwts. and is of considerable intricacy as is evident from the section lines imposed on the upper illustration. The lower photograph shows one of these castings after being fired at with a $4\frac{1}{8}$-in. armour-piercing projectile weighing 31 lbs. The striking velocity was 1210 f.s., and the striking energy 315 ft.-tons; the part fired at presented four thicknesses of steel which were perforated without cracks of any kind being produced.

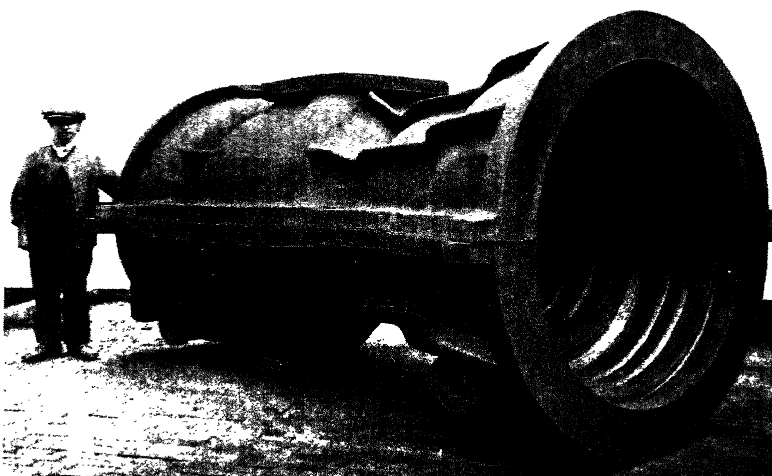
The results of tests to destruction on a locomotive driving wheel centre, 6 ft. 3 in. in diameter, made of best toughened cast steel, are shown by the upper illustration on Plate XXXIX. For the first test the wheel centre was suspended vertically and allowed to fall sixteen times, from heights varying from 3 ft. to 45ft., on to a solid block of steel weighing over 5 tons, embedded in concrete. By this test certain parts of the rim and spokes were distorted, but otherwise the wheel was perfectly sound with no sign of fracture. For the second test the wheel was placed in various positions and a tup weighing 3 tons was allowed to fall upon it twelve times from a height of 45 ft. The fractures produced by this severe test showed that all parts of the wheel were perfectly sound.

The lower illustration on Plate XXXIX shows a casing of best toughened cast steel for a Parsons steam turbine. The two pieces forming this casing are interesting on account of their size and intricacy, as well as by reason of the conditions which they have to withstand in service. Amongst the many other important applications of toughened steel castings, mention may be made of housings for rolling mills (shown in Plate XL) the weight of such housings being, in some instances, nearly 40 tons. There are also the structural parts of jawbreakers and gyratory crushers which are used not only in mining service but also for reducing stone, slag, etc., to road metal sizes.

A casting of different nature is shown in the lower part of Plate XL, this being a high permeability magnet casting, weighing more than 26 tons. High permeability castings for dynamos and other electrical machinery require very special care to ensure both that the steel is of the requisite high standard of magnetic quality, and also that this quality is not nullified

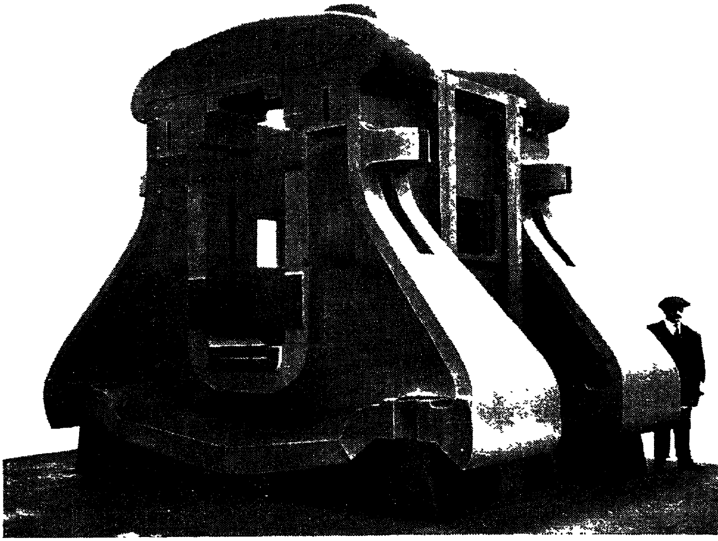


LOCOMOTIVE DRIVING WHEEL CENTRE AFTER TESTING TO DESTRUCTION.



CASING FOR PARSONS STEAM TURBINE.

To face page 152



Housing for Rolling Mill.

High Permeability Magnet Casting.

by porosity or unsoundness; otherwise the designer, after satisfying himself as to the characteristics by means of a permeability test obtained from a coupon on the magnetic casting, may meet with disappointment in the subsequent performance of the completed machine. The best guarantee, therefore, is the experience of the steel-maker in the production of such castings. While steel castings of high permeability have a tenacity of about 26 tons per sq. in., they have not usually to withstand any definite applied stresses. Where, however, such is the case, and tenacities higher than this figure are demanded by the conditions, metallurgical knowledge renders it possible to supply castings of the highest possible permeability combined also with mechanical toughness consistent with such strength.

As regards forgings, the first essential to soundness in the forged metal, as well as to economy in manufacture, is the use of correct methods in casting the ingots.

The author has repeatedly emphasized the importance, from the national point of view, of reducing the amount of waste to be cut away from the upper part of cast ingots. In a paper entitled "A Method of Producing Sound Ingots," read before the Iron and Steel Institute in 1912, he described processes of casting ingots by which it is possible to guarantee the soundness of the finished forging whilst, at the same time, effecting important reductions in the amount of material to be cut away from the top of the ingot. These processes are in regular use at the works of the author's firm with very satisfactory results.

One of the most important applications of forgings is in shafts for all purposes, and the results of tests indicating the quality of such products are shown on Plate XLI. The forged motor truck axle here illustrated was drop-tested with a tup weighing 1 ton and withstood no less than 60 drops from an average height of 21 feet without sign of fracture. Notwithstanding the high elastic limit of the steel used, viz., 25 tons per sq. in., with a tenacity of 43 tons per sq. in., the material was so tough that the axle bent only $18\frac{3}{8}$ inches as a result of drop tests representing 1,278 foot-tons of energy.

Marine shafts of the type shown on Plate XLII are supplied in lengths up to 30 feet. The portion of the particular shaft illustrated, 19 inches in diameter, was attacked by three $4\frac{1}{2}$ inch armour piercing projectiles with a total striking energy of

1,410 foot-tons. The steel successfully resisted this severe test without showing any tendency to crack. The No. 3 impact was the most severe, the 40-lb. projectile striking with a velocity of 1,526 f.s., representing 570 ft.-tons of energy ; the penetration in this case was $5\frac{1}{2}$ inches. The mechanical tests on this forging were :—Yield point 29 tons per sq. in. ; maximum stress 46 tons per sq. in.; elongation 27 per cent.; reduction in area 53 per cent. As a cast product, thousands of tons of this material have been used for conning towers, ammunition tubes, and other parts of warships which have to pass a severe firing-proof trial before acceptance.

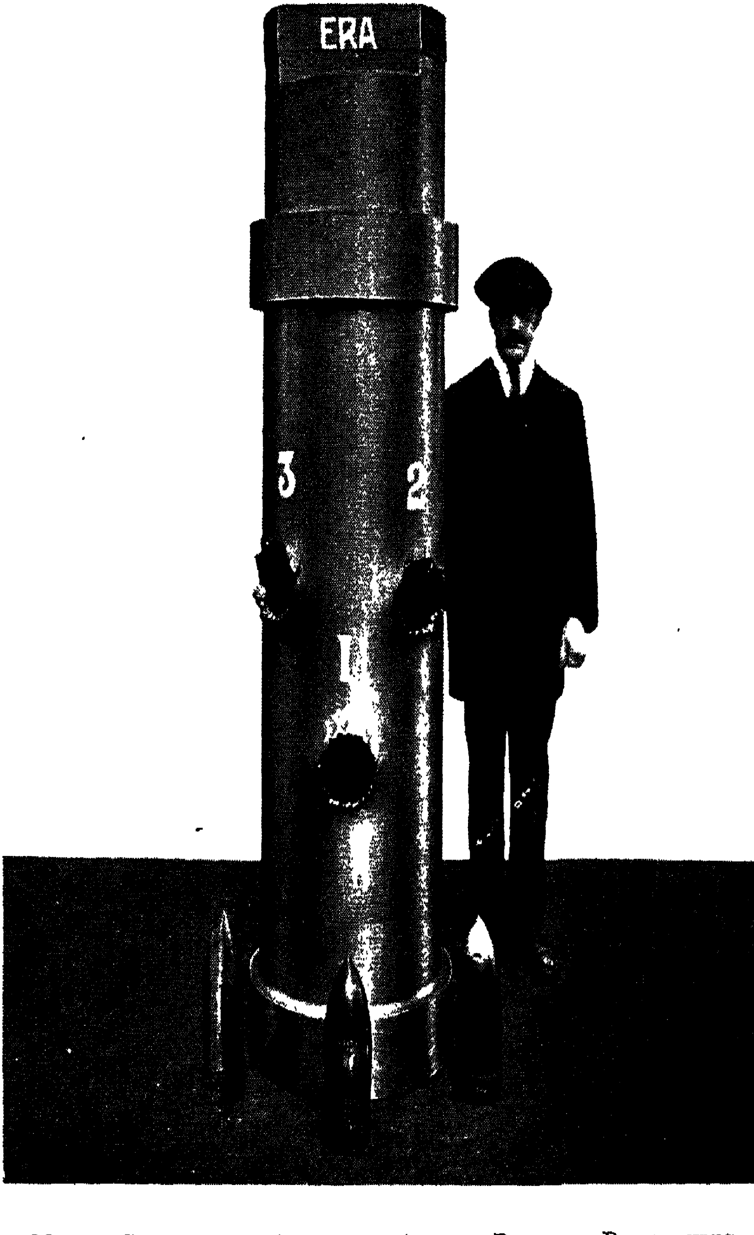
Forgings, such as rotor forgings, required by the electrical industry to possess a combination of both high magnetic permeability and specified mechanical strength and toughness, have been the subject of considerable research, and such forgings, in both plain carbon steel and nickel steel, are now produced with the best possible characteristics in both directions.

High Tenacity Steels.—Modern engineering construction demands high duty from the steel employed, both in point of efficiency—as for example, in the aeroplane, where the weight per horse-power must be a minimum—and in point of reliability and durability. The renewal of wearing parts increases running expenses, not only in the actual cost of replacements, but also in the less readily estimated expenditure due to plant being out of service for purposes of renewals.

By correct heat-treatment of carbon steels of appropriate composition remarkable hardness and tenacity can be attained, and for many purposes carbon steel castings and forgings admirably meet the requirements of service. In other cases, however, high tenacity carbon steels lack sufficient toughness to meet the requirements of modern engineering, and although improved metallurgical knowledge—derived largely from research and experience with alloy steels—has shown how to obtain the best qualities from carbon steel, the number of cases in which carbon steels are inadequate is steadily increasing.

Herein lie the special advantages of alloy steels possessing both hardness and toughness or ductility, so that they can be used under abnormally difficult conditions with as high a factor of safety as ordinary mild steel under its usual working conditions.

MOTOR TRUCK AXLE AFTER DROP TUP TESTS



Marine Shaft after Attack by Armour-Piercing Projectiles.

Leaving out of consideration manganese steel, which has already been dealt with fully in Chapter VII, high tenacity engineering steels are mainly, but by no means invariably, of the chromium, nickel, or nickel-chromium type, sometimes with the addition of other elements.

The addition of chromium to steel, in the presence of carbon, has the effect of hardening the metal, and reducing the tendency to granular structure. In conjunction with nickel or vanadium, this element gives alloys which are exceptionally strong and resistant to wear, yet can be machined easily. Such steels are therefore employed for high-class gearing, the crankshafts of internal combustion engines, and other special parts of machines.

In all cases, correct heat-treatment is essential to the development of the advantageous properties of chromium steels. Even a small percentage of chromium improves the homogeneity, strength, and wearing qualities of steel, and increases the elastic limit to 80 per cent. or more of the ultimate strength without appreciable loss of ductility.

Chromium steels containing 0·5 to 3·0 per cent. of chromium, and from 1·3 to 0·3 per cent. of carbon, are used for various constructional components in which hardness, combined with toughness and strength, is required.

Where wear and abrasion are the primary considerations, apart from manganese steel, plain chromium steel with a comparatively low percentage, 1 to 2 per cent. of this element, has proved itself of considerable service in the form of both castings and forgings. A high tenacity steel, hard, tough, and resistant to wear, suitable for use in the balls, rollers, and races of ball and roller bearings, contains about 0·8 to 1·0 per cent. of carbon and 1·2 to 1·6 per cent. of chromium. Its ultimate strength may be as high as 130 tons per sq. in., when the metal is suitably heat-treated. Steels with higher percentages of chromium have remarkable powers of resistance to corrosion and are considered later in this chapter.

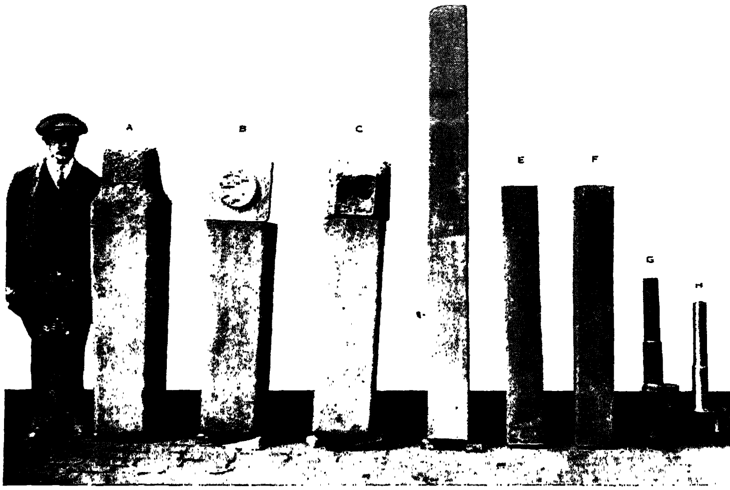
Though there are certain difficulties in the manufacture and working of vanadium steels, these alloys are employed successfully for special shafts, gears, and tools for punching, shearing, and drawing. Their uses will probably extend, the general effect of vanadium in conjunction with proper heat-treatment being to improve the structure of the steel and increase the resistance of the metal to shock and fatigue.

The addition of 1 or 2 per cent. of manganese increases the strength of carbon steel and, in conjunction with appropriate heat-treatment, gives other desirable properties. The applications of low manganese steels—which must not of course be confused with the author's manganese steel containing about 13 per cent. of manganese—include axles, tyres, shear blades, and other parts demanding strength and resistance to shock.

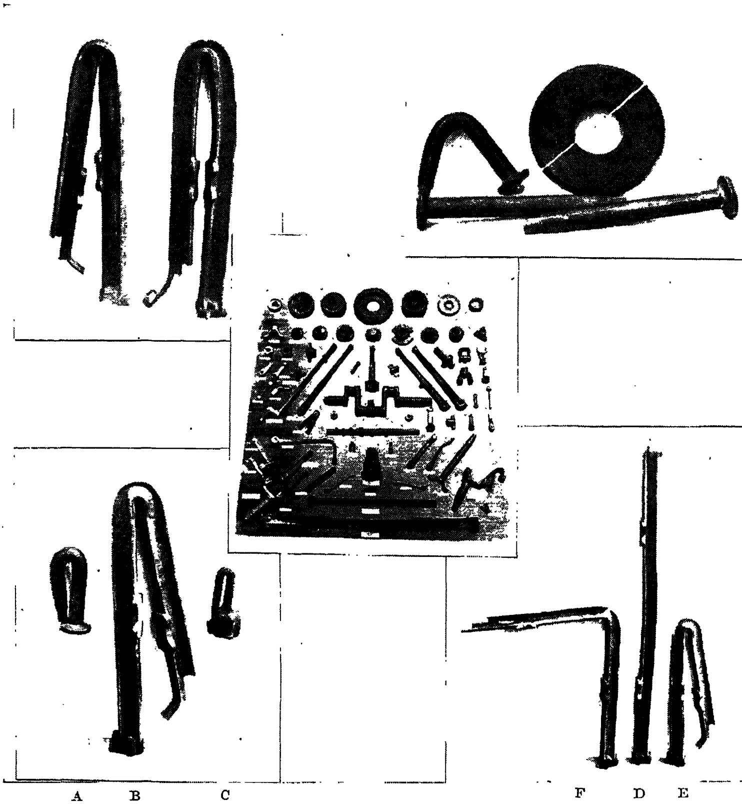
In the space here available it is impossible even to outline all the applications of high-tenacity alloy steels, but it may be pointed out that these materials are essential in the construction of aeroplanes and motor vehicles, so that with the growing use of these means of transport there is opening an enormous outlet for alloy steels. In America, where the motor car is in more general use than in this country, the statistics of four prominent firms for the year 1922 show that of nearly 1 million tons of steels of all kinds and forms used by these firms in the construction of their cars, about 150,000 tons, that is, 15 per cent., were alloy steels.

The stages in the evolution of an aeroplane crankshaft are illustrated by Plate XLIII. At *A*, *B*, and *C*, there are shown ingots of special steel as cast by the author's patent methods; the small amount of waste resulting from these methods and the soundness of the ingot itself are shown by the bottom and top appearance, at *B* and *C* respectively, of the piece cut from the top of the ingot. The billet *D* forged from these ingots is shown cut to length at *E* and *F*, whilst *G* shows the forged crankshaft and *H* the finished product.

The remarkable combination of toughness, tensile strength, and shock-resisting qualities which the metallurgist can offer in special steels for automobile parts, is shown by Plate XLIV. This illustration shows at *A*, a clutch coupling shaft, quenched and tempered, of 50 tons per sq. in. tenacity; at *B*, a front axle, normalised and of 45 tons tenacity; and at *C* a connecting rod, normalised and of 45 tons tenacity. Though each of these pieces has been bent double cold, there is no sign of fracture. In the lower illustration, Plate XLIV, there is shown at *D*, a front axle stamping of the special steel known by the name "Era 51"; a stamping of this material can be bent double cold under the steam hammer without showing any sign of cracking, see *E*, Plate XLIV. A similar axle of 3½ per cent. nickel steel when subjected to the same test fails as shown at *F*. Further evidence as to the excellent toughness and shock-



STAGES IN THE EVOLUTION OF AN AEROPLANE CRANK SHAFT.



SPECIAL STEELS FOR AUTOMOBILE PARTS, INCLUDING CLUTCH COUPLING SHAFT, FRONT AXLE STAMPING, AND DROP FORGINGS.

resisting qualities obtainable from the "Era 51" steel by simple normalising, is given by the test data in Table X.

TABLE X

MECHANICAL TESTS ON NORMALISED SPECIAL STEELS.

	"Era 51" Steel.	$3\frac{1}{2}$% Nickel Steel.
TENSILE TEST :—		
Yield point, tons/sq. in.	32	36
Maximum stress, tons/sq. in.	45	47
Elongation, per cent.	35	29
Reduction of area, per cent.	65	57
FREMONT SHOCK TEST ; NOTCHED :—		
Kg.-metres	16·3	8·7
Angle of bend, degrees	65	22
Brinell hardness number..	192	202

A striking example of the extent to which special steels enter into the construction of vital components in a modern automobile is afforded by Plate XLIV, which shows drop forgings as used in the Bean car. In this "All British" car, made by Messrs. Harper, Sons & Bean, Dudley, all the working parts, including the axles, crankshaft, gears, and springs, are made of special alloy steels produced by the author's firm. In order that the highest possible quality and unvarying uniformity may be attained, every heat or cast is "inspected" by full analysis before the steel is allowed to be worked up. The greatest care is also taken in forging and rolling, all this work being controlled, as are the subsequent operations of hardening and tempering, by numerous pyrometric observations.

This car has already won many trophies, and one of its most important and recent successes is the extraordinary journey accomplished in crossing Australia from North to South, representing a total distance of 6,200 miles, with a load averaging 24 cwts. To Mr. J. L. Simpson, Mr. Francis Bertles the Australian explorer, and Mr. M. H. Ellis belongs the credit of being the first to make a double crossing of the Australian continent by motor car.

In May, 1924, the Syndicated Press of Australia organised an effort to cross the continent from Sydney in the South East,

to Port Darwin at the Northern end of the Gulf of Carpentaria, a journey which had never been previously accomplished, and, if possible, to return by another route overland, making a total distance of 6,200 miles. By far the greater part of this journey was through the virgin bush without roads or tracks of any sort, and, as may be imagined, all kinds of natural obstacles had to be tackled just as they came. A 14 H.P. Bean car was chosen for the attempt, partly because it was a British car and partly because it had put up such a fine performance in the Australian Alpine trials. It carried three passengers and all their supplies, camping kit, and other oddments, together with fuel and oil for stretches, the longest of which was 1,320 miles, making a total load for this small touring car of 28 cwt.

It is difficult to choose which to admire most, the courage of the men who set out on such an undertaking, or the endurance of a car to survive this severe test ; but survive the ordeal it did. The only casualties encountered other than those with tyres were the cross-steering tube, carried away by a rock, and a dumb iron bent through dropping into a washout. These had to be remedied with the tools carried on the car. On one occasion a mishap occurred to the reserve oil supply being carried, and a run of 120 miles had to be made with beef dripping as lubricant instead of engine oil ! These details illustrate what a modern car can do when constructed of the most modern design and of the best material.

In the field of heavier mechanical engineering construction, the introduction of alloy steels will necessarily take some time, although their development and use in the form of quite large forgings and castings for ordnance purposes should give confidence in their applications in other directions. In connection with locomotives and rolling stock on railways, alloy steels have been used to a limited extent for such purposes as crankshafts and axles with excellent results which, it is hoped, will lead to more extended use.

Special Structural Steels. — In structural work, as distinct from machinery, *e.g.*, in the steel frames of buildings, and the bridges and piers in which our civil engineers have shown so much creative skill, the use of alloy steels has hitherto made comparatively little headway. Doubtless the large quantities of steel used in some of these constructions, and the enormous cost of these works, demand earnest consideration before any change of practice can be introduced, and a high

degree of conservatism is necessary. The design of still larger bridges must necessarily be based upon the performance of existing structures, and the introduction of new and untried materials, however suitable their qualities appear, may be difficult and uncertain without experience of their actual use over a period of years. For this, if for no other, reason the construction of a bridge in high tenacity steel would require a great deal of courage on the part of the engineer whose reputation depends upon the success or failure of his work.

Apart from these considerations, the working up of alloy steels into large rolled sections for girders and plates would require modifications in existing plants. Progress in this direction, therefore, however suitable the qualities of certain alloy steels may appear, must necessarily be very gradual, and the position as regards ship construction is somewhat similar.

Departures from the established use of mild steel and wrought-iron have, however, been made in some cases, both bridges and ships of high-tenacity steel having been designed and built. As already noted in Chapter VIII, steel of about 40 tons tenacity was used in the construction of the *Lusitania* and *Mauretania*, this relatively high strength being obtained by the addition of a moderate percentage of silicon, nearly 1 per cent.

The foregoing remarks apply more particularly to structures as a whole. It has naturally been found that, in the case of certain details, alloy steels could be used advantageously. For example, the use of steel in the construction of warships places the magnetic compass under such disadvantage from the superior magnetic attraction of the ship itself, compared with the influence of the earth's directive force, that in certain cases it has been found necessary to make use of the non-magnetic qualities of manganese steel by adopting this alloy for some portions of the structure close to the compass position.

The advantages of using non-corrodible steel for bridges and other civil engineering structures are receiving serious attention because, apart from the great annual expenditure in their maintenance by painting and other means of protection, constant and alert supervision is necessary, after a period of years, to ensure that corrosion is not undermining the structure at some vital point. Painting is not always a sufficient safeguard, and in large structures there are always more or less inaccessible parts to which it is difficult to give the necessary attention.

Nickel steels are particularly valuable for structural purposes,

the addition of nickel to carbon steel resulting in an increase of strength, ductility, and toughness, and a higher ratio of elastic limit to ultimate strength. The nickel steels, containing from about 1 to 10 per cent. of nickel and from 1·65 per cent. down to zero carbon, resemble carbon steels, but are superior to the latter. The alloys within this range are of great practical value.

Steels containing from 2 to 4 per cent. of nickel and from 0·2 to 0·5 per cent. of carbon are used extensively for constructional purposes. Their applications include machine and engine parts, seamless tubes for bicycles, the frames of large dynamos, gun and marine forgings, special shafts and axles, and the members of large bridges or other structures in which the superior mechanical properties of the alloy steel outweigh its higher cost, as compared with simple carbon steel.

A steel containing 3½ per cent. of nickel and 0·25 per cent. of carbon has the same tensile strength as a 0·45 per cent. carbon steel, and an elastic limit about 60 per cent. of the ultimate strength, as compared with 50 per cent. for the simple carbon steel. Nickel steel is tough under impact, and its ductility is well preserved at low temperatures, even down to the temperature of liquid air. The resistance to fatigue is particularly marked, and this is a specially valuable property where structural applications are concerned.

The combined effect of nickel and chromium in nickel-chromium steels is to produce a material with excellent physical properties, well-suited to a great variety of structural applications. According to the conditions to be met, from 1·25 to 3·0 per cent. of nickel and from 0·6 to 1·25 per cent. of chromium are employed, the ratio of nickel to chromium being approximately 2½ to 1, and the percentage of these elements being greater for higher working stresses, particularly in regard to dynamic loads. The general effect of nickel and chromium when used together is to raise the elastic limit of steel and increase its ductility, hardening power, and resistance to wear. Heat-treatment is required to develop fully the properties of these alloys, and maximum strength combined with satisfactory ductility is obtained in the air-hardening steels which contain more than 5 per cent. total of nickel, chromium, and carbon. The high qualities obtainable in alloys of this type are exemplified by a nickel-chromium steel recently made by the author's firm with the following properties: Tenacity, 108 tons per sq. in.; elastic limit, 90 tons per sq. in.; elongation, 15 per cent. with

51 per cent. reduction of area ; ball hardness, 477 ; and Frémont shock test, 5·3 kg.-m. with 70° angle of bend. The high value of the impact test figure is indicative of the dynamic strength which makes nickel-chromium steels so useful for parts which have to resist shock and live loads.

The comparative cheapness and easy machineability of nickel-chromium steels are strong points in their favour, and these alloys are used satisfactorily in automobile construction, for bridge girders, and for gearing and other special components, as well as for the armament purposes mentioned later.

Non-Corrodible Steels.—It is hardly possible to mention a greater potential field of utility for special steels than that afforded by the campaign against the ravages of corrosion. The author some time ago made an approximate estimate of the world wastage due to the corrosion of iron and steel, which seems to have served a useful purpose by attracting attention to the magnitude of the economic loss which is being sustained from day to day due to this cause. As a conservative estimate, the author placed this figure at about £500,000,000 per annum. If the use of alloy steels can do something to mitigate this loss, as the author believes to be the case, it could serve no more useful purpose; he has fully dealt with this subject in a paper entitled "The Corrosion of Ferrous Metals," read in April, 1922, in connection with his work for the Committee of the Institution of Civil Engineers on the "Deterioration of Structures Exposed to Sea Action."

Corrosion losses, although in the main arising from the action of "wind and water," are by no means confined to these. Special industries, in particular the manufacture of chemicals, bring about the corrosion of steel in a variety of other ways. It is therefore not a simple problem to provide a universal panacea from the field of alloy steels; in fact, up to the present time, there has been no discovery of a steel which is universally resistant to corrosion of all types and at the same time producible at an economic cost.

In describing the steels of a non-corrodible character now available, it is therefore necessary to refer to different types and the special directions in which they are useful.

Types of Corrosion.—The types of corrosion usually encountered in practice may conveniently be classified as follows:

(*a*) Corrosion from ordinary atmospheric effects.

(*b*) Corrosion from special atmospheric conditions—*e.g.*

in manufacturing centres, where the air is charged with corrosive fumes, etc.

(*c*) Corrosion in special media, such as gases, acids, or other liquids.

(*d*) Corrosion by heating under oxidising conditions, generally called scaling.

(*e*) Losses by erosion, though purely mechanical in nature, may fairly be considered under the heading of corrosion.

Rust-Resisting Steels.—It has been pointed out by Dr. Aitchison and others that the term " rustless steel " applies not to a single alloy but to a group of steels containing between 11 and 15 per cent. of chromium, and usually less than 0·45 per cent. of carbon. Their evolution has been the product of many minds and much research, particular credit being due to Messrs. Thos. Firth & Sons, Mr. H. Brearley, and Dr. W.H. Hatfield for their work in this field.

In his paper on " Stainless Steels," read before the Midland Institute of Mining, Civil, and Mechanical Engineers in 1922, Dr. Hatfield states that " it was in 1912–13 that Mr. Harry Brearley discovered that the 12 per cent. to 14 per cent. chromium steels, when in the hardened condition, resisted successfully general atmospheric and many other active influences which lead to corrosion."

The first correlated study, as far as can be ascertained, of chromium steels published in this or any other country, was contained in the author's paper on " Alloys of Iron and Chromium," presented to the Iron and Steel Institute in 1892. During the preceding two years investigations had been made on a series of fifteen alloys containing from 0·22 to 16·74 per cent. of chromium and up to 2·12 per cent. of carbon. Amongst these alloys there were four which may be regarded as the forerunners of the present-day rustless steels; their compositions were as follows:

	Carbon	Silicon	Chromium
	Per Cent.	Per Cent.	Per Cent.
Specimen L . .	0·71	0·36	9·18
„ M . .	1·27	0·38	11·13
„ N . .	1·79	0·61	15·12
„ O . .	2·12	1·20	16·74

As stated in the paper mentioned, specimen L was quickly corroded by sulphuric acid, and from these researches there emerged the fact, since confirmed by experience, that alloys of iron with high percentages of chromium were of no value under this particular type of test. The loss in the case of specimen L when immersed for twenty-one days in 50 per cent. (volume) sulphuric acid was 5·64 per cent. compared with 7·48 per cent. for mild steel and 44·7 per cent. for wrought-iron tested under the same conditions.

This same paper to the Iron and Steel Institute was accompanied by a valuable report from the great French metallurgist, the late Professor Floris Osmond, in which he said, concerning specimen L :

"As regards the specimen annealed at 1320° C. . . . the transformation of the matrix into hard metal 'little capable of being reacted upon by acids,' and no longer showing the reaction of hardening carbon, is almost complete."

The same facts applied to the steels M, N, and O, and in his conclusions regarding these alloys Osmond stated that, as the amount of chromium increased, a compound of iron, chromium, and carbon appeared to be formed which was only partly attacked by acids and possessed great hardness.

This early work was upon steels the composition of which was analogous to those now known and used as "rustless steels." There is an added interest in the fact that specimen M, and several similar specimens in the shape of tensile bars, when examined twenty-three years after the date of their preparation, were found on the whole quite bright and practically free from rust. These steels were not developed further at the time, because it was then impossible to obtain chromium or ferro-chromium of the required low-carbon type at prices which would enable industrial products to be manufactured. Great credit is due to the workers who have since commercialised the preparation and application of these valuable alloys.

The resistance of chromium steels to corrosion varies widely with the corroding agent employed, and with the heat-treatment and mechanical treatment to which the material is subjected. Rustless steel, suitably heat-treated, is practically unaffected by fresh or salt water, the organic acids of fruits, vinegar, nitric acid of any strength, and ammonia. On the other hand, it is not resistant to sulphuric acid and caustic alkalis, and it may

be etched by a mixture of concentrated hydrochloric and nitric acids. Maximum resistance to corrosion is obtained when the steel is in the hardened condition and when it is free from the strains produced by cold-working scratches, or deformation of any kind.

The type of " rustless steel " which has found most practical applications up to the present time is steel containing about 13 per cent. of chromium. Steel of this composition is generally resistant to most forms of corrosion, including atmospheric action. It rather fails against sulphuric acid, but even in this respect it is an improvement on ordinary steel. For the conditions to which cutlery is ordinarily exposed, chromium steel, when properly heat-treated, retains its original polish unsullied. This high standard need not be attained in all industrial applications, for, in many cases, although the surface of the steel may become tarnished or rusty, the requirements are met because the actual loss of material by corrosion is much slower than with ordinary steel. Chromium steel may behave in this manner under some forms of corrosion or where the best method of treatment is not practicable.

Apart from its use for cutlery of all classes, and for the majority of metal work and metal fittings in all buildings where good appearance is a consideration, rustless steel is likely to find an increasing number of industrial applications, in workshops and factories, and even in heavy engineering constructions, such as docks, ships, and bridges. Forged pump rams made of rustless chromium steel at the Hecla Works, Sheffield, have been found to be far superior to both simple steel and phosphor-bronze in point of durability under conditions favouring corrosion and wear. Plate XLV shows the excellent condition of valves made from non-rusting steel after 17 months use in hydraulic pumps. Similarly, hydrophone diaphragms made of " Galahad " non-rusting steel, for use in submarine service during the war, were found to be practically unaffected by six months' immersion in sea-water, whilst the hardness and high elastic limit of the rustless steel rendered this material acoustically superior to nickel steel.

An important point in relation to the use of rustless steel and, to a lesser extent, in the use of rustless iron, is that suitable treatment is necessary if the best non-corrodible qualities are to be obtained in the metal. The excellent mechanical qualities of chromium steel, when properly heat-treated, make this alloy

NON-RUSTING STEEL VALVES FOR HYDRAULIC PUMPS.

useful for highly stressed members where these have to be non-corrodible.

Rustless Iron.—The ferro-chromium used in the manufacture of rustless steel contains from 1 to 2 per cent. of carbon. If ferro-chromium practically free from carbon be used, there is obtained " rustless iron," *i.e.*, rustless steel containing about 0·1 per cent. of carbon. Due to its greater softness and malleability, rustless iron can be forged, stamped, pressed, and machined more easily than rustless steel. The tensile strength of these rustless alloys increases with the carbon content and is approximately as follows:

Carbon per Cent.	Tensile Strength, in Tons per Sq. in. according to Heat-Treatment.
0·1 to 0·2	40 to 80
0·2 „ 0·3	45 „ 90
0·3 „ 0·4	50 „ 105

Though the tensile strength of rustless iron is thus distinctly lower than that of rustless steel, it is sufficiently high to make the alloy useful for general constructional purposes, and amongst its applications, present and prospective, may be mentioned sheets for the body work, shields, and wheel discs of motor cars, seamless tubes, wire, drop forgings, and utensils, accessories, and fittings of all descriptions, where a good finish and resistance to corrosion are required.

Pure Iron.—Although in the opposite sense to alloying, mention should be made of the material known as " Armco " iron, which is really iron of a high degree of purity made by the open-hearth steel process. Dr. A. S. Cushman, of Washington, D.C., has published many valuable papers dealing with the subject of corrosion, and from his investigations it appears that " Armco " iron, whilst containing no chromium, and only 0·10 per cent. or even less total impurities, is highly resistant to many forms of corrosive attack.

In this connection it is interesting to note the analyses of the Delhi pillar and of Murdoch's gasometer, see also Chapters II and IV respectively. These analyses are as follows:

	C	Si	S	P	Mn	Cu	Fe
Delhi pillar ...	0·080	0·046	0·006	0·114	Nil	Nil	99·72 per cent.
Murdoch's gasometer	0·04	0·28	0·045	0·55	0·07	0·02	98·90 per cent.

The percentage of carbon is low in both cases and, though the total impurities—amounting to 0·28 per cent. in the Delhi pillar and about 1·00 per cent. in the gasometer metal—hardly allow these materials to be described as "pure iron," yet the wrought-iron pillar resisted exposure for 1600 years, whilst the wrought-iron plates of the gasometer, under much more severe conditions, were in use for nearly 120 years.

Alloys Resisting Special Forms of Corrosion.—Widely divergent opinions have been expressed concerning the value of copper in steel as a preventive of corrosion, these differences being probably attributable to the effect of copper varying greatly with the corrosive agencies concerned. It is a remarkable fact that ordinary mild steel containing so little as ¼ per cent. (one part in 400) of copper has greatly improved resistance to attack by sulphuric acid and by the sulphurous atmosphere of industrial districts.

Steels containing 14 or 15 per cent. of silicon combine high resistance to corrosion by commercial acids with sufficiently good mechanical properties to enable them to be used for containing vessels, pipes, and fittings in the manufacture and handling of acids and other chemicals. Alloys containing about 20 per cent. of silicon are even more resistant to corrosion, but they are rather brittle, and can only be used in the cast form.

The addition of nickel to carbon steel generally reduces the corrodibility of the metal very appreciably, and it is found that boiler tubes containing 30 per cent. of nickel last about twice as long as mild steel tubes.

Steel containing 22 per cent. of nickel resists many corrosive agents, and it is used for valve parts exposed to salt water and for the electrodes of sparking plugs. With higher percentages of nickel the alloys remain resistant to corrosion, tough and dense, and the coefficient of thermal expansion decreases until the percentage of nickel reaches 36 per cent., beyond which it rises again. A nickel steel containing 36 per cent. of nickel and the lowest attainable percentage of carbon is known as "Invar," and has the valuable property of being almost unaffected by temperature changes within the range from atmospheric temperatures up to 300° C. Its coefficient of linear expansion is about 0·0000004 per 1° C., and the alloy is therefore most useful in the construction of standards of length, parts of precision instruments, balance wheels for watches, and pendulums for clocks. Boiler tubes of this composition have

been found to last three times as long as carbon steel tubes in marine service, and "Invar" wire coated with copper has a net coefficient of expansion which can be made equal to that of any kind of glass into which it is desired to seal the wire.

Nickel-chromium steels resisting the corrosive action of the atmosphere, sea-water, and certain acids and gases, contain from 10 to 15 per cent. of chromium, with 1 to 3 per cent. of nickel, or from 20 to 23 per cent. of chromium with 6 to 9 per cent. of nickel, the carbon content being from 0·1 to 0·3 per cent. in both cases. These steels have a tenacity of about 50 tons per sq. in., and a satisfactory elastic limit and ductility. The first-mentioned one has been used for turbine blades, and the second one (with the higher percentages of nickel and chromium) for valve spindles.

Steels for Steam-Turbine Blades.—The development of the steam turbine, and steam plant generally, in the direction of higher efficiency is leading to the use of steam at higher pressures and higher temperatures and, with the ever-increasing demand for higher temperatures and pressures there has arisen a need for steel which retains, not only considerable strength at high temperatures, but also considerable hardness to withstand the erosive action of high velocity steam, and marked resistance to corrosion. The degree of resistance to corrosion is a particularly important consideration in marine turbines and in land turbines situated near the coast, where salt water may, by one means or another, find its way into the turbine.

Nickel steel containing from 3 per cent. to 7 per cent. of nickel has been used extensively for the blades of steam-turbines, and, in some cases, with very satisfactory results. In other cases, particularly in marine turbines, trouble has been experienced due to corrosion; this also occurs at the low pressure end of some land turbines, where a certain amount of corrosion takes place. Periods of disuse are found to result in increased corrosion.

Bronze is used in some instances, and nickel steels containing about 30 per cent. of nickel have been used, though not with complete success.

High chromium steel of the type already mentioned has shown itself to be capable of excellent results, but the necessity for heat-treatment is an important disability, because this may be upset in the assembly of the turbine, which often involves brazing, welding, or even casting the blades in the

disc. Also, unless the surface of the blades be very highly finished, surface defects act as centres of corrosion.

An important advance has been effected by the discovery of a new alloy steel as a result of research work carried out over many years by a group of eminent French metallurgists, including M. Chevenard, of the Commentry-Fourchambault et Decazeville Compagnie, also MM. Guillaume, Fayol, Muguet, and Girin. The author's firm is also trying to improve and develop this material, as well as other similar special products. The non-corrodible qualities of this material, excellent at ordinary temperatures, are retained at high temperatures. Its strength is also well maintained, a tenacity of 42 tons per sq. in. being obtained even at 450° C., associated with high resistance to erosion. This alloy is perfectly stable, and is therefore unaffected by brazing, welding, or casting, or by continuous use over long periods. It does not require heat-treatment, and a high degree of surface finish is unimportant as regards the corrosion-resisting qualities of the alloy. This new material has already been applied to a considerable extent, and highly favourable reports have been received from users.

The extent of the progress made by steel metallurgists in the campaign against corrosion—using the term in its widest sense—is perhaps not fully realised by engineers, who may find on closer examination that suitable steels are already available to meet their particular problems, or, alternatively, that there are steels better than those at present employed, in point of mechanical properties under the working conditions concerned.

Heat-Resisting, Non-Scaling Steels.—With the development of high temperature processes, or the call for higher performance from existing types of plant, there is ever-increasing demand for material to resist the destructive effects of high temperatures.

In order that a steel may be termed "heat resisting" in the sense here intended, it should retain useful mechanical properties at high temperatures, and it should be subject to little or no "scaling" when exposed to high temperatures in an oxidising atmosphere.

It is well known that, at temperatures above red heat, ordinary steels become plastic and possess little strength, so that they cannot be relied on to sustain the slightest load at such temperatures. In addition, the oxidation or scaling effects at such temperatures often lead to great wastage of

material and involve frequent replacements. Such action, in fact, may be regarded to some extent as a corrosion effect greatly enhanced by increased temperature. These failings of ordinary steel handicap the engineer in his progress in many directions, and the removal of these limitations by the use of alloy steels constitutes a worthy object for the metallurgist.

High chromium steel possesses useful characteristics in both these directions, maintaining a considerable degree of strength, and scaling to a much less degree than ordinary steel up to moderately high temperatures. It finds therefore useful applications, as in valves for automobiles, but these applications are limited because the desired qualities are not retained far enough to meet the full demands of engineering practice. The strength of this steel falls away rapidly at temperatures above 650° C. and it practically loses its non-scaling characteristics at 850° C. Consequently, for example, it is unsuitable for the valves of high-duty aeroplane engines, or for such articles as the boxes in which steel parts are heated with their carbonising mixture for case-hardening, the temperature in this instance reaching 1000° to 1100° C.

Both chromium and tungsten steels are used extensively in the manufacture of valves for petrol engines. Investigations by Professor A. H. Gibson, D.Sc., and Mr. H. Wright Baker, M.Sc., described in their paper on "Exhaust Valve and Cylinder Head Temperatures in High-Speed Petrol Engines," before the Institution of Mechanical Engineers (Dec. 1923), show that the temperature of the exhaust valve, in an air-cooled or water-cooled engine with over-head valves, may be between 600° C. and 750° C. under normal conditions. At such temperatures both chromium steel and tungsten steel are capable of giving excellent results, but chromium steel has the advantage of not oxidising so rapidly as tungsten steel with weak mixtures. If pre-ignition occurs, the temperature of the valve may exceed 800° C. and the valve, whether of chromium or tungsten steel, will rapidly burn out.

Steels of the type used for high-speed cutting tools, including those of the tungsten-chromium and cobalt-chromium types, retain a high degree of strength up to about 650° C., but, as in the case of high chromium steel, their strength falls away rapidly at higher temperatures. For this reason they also have found only a limited amount of use for such articles as

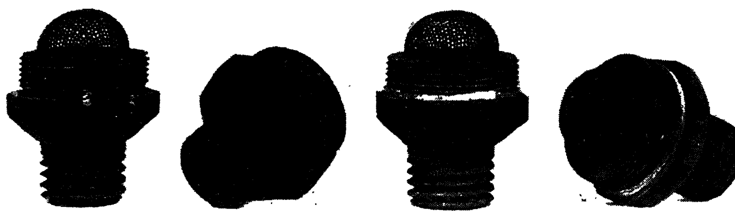
motor car valves, and they have got the further disability of not possessing non-scaling characteristics to any marked degree.

The addition of silicon, in amounts up to about 3 per cent., has been found to produce a marked improvement in high chromium steel, specially in non-scaling characteristics, and in addition to improve its strength to some degree at high temperatures. Beyond, however, about 800° C. the qualities are still below practical requirements in many directions.

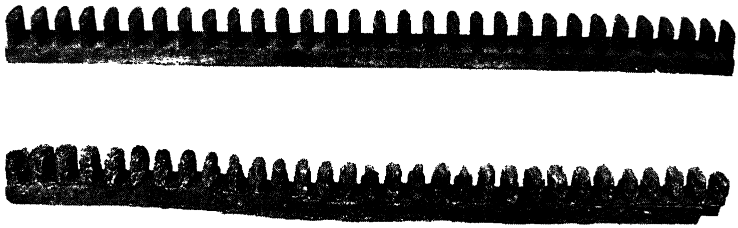
There are non-ferrous alloys, containing nickel and chromium, which are used in the electrical industry, as they possess high electrical resistance and are useful for heating elements in view of their resistance to scaling; also several other purposes such as carbonising boxes, pyrometer tubes, and other objects. Owing to the fact that such alloys usually contain about 60 per cent. of nickel they are expensive, and although there are undoubtedly cases where the use of high priced materials is justified by results, a less expensive material is desirable for more general use.

A more recent product, known as "A.T.G.," has advantages, specially in the direction of its strength at high temperatures and the ability with which it will endure sustained loads at high temperatures without gradually stretching. This is an essential requirement in such applications as the gas cylinders used in the production of nitrogen by the Claude process, and for this and other similar purposes "A.T.G." has been found superior to any other material known.

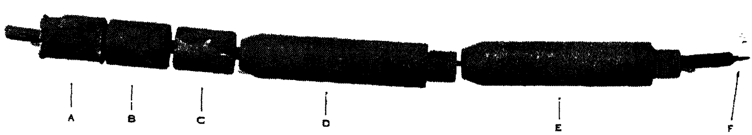
The alloys suitable for high temperature work hitherto produced are all of an expensive nature, and to meet the demand for a steel of reasonable cost possessing the highest possible strength and non-scaling qualities at high temperatures, there has been produced the material known as "Era" heat-resisting steel. The non-scaling qualities of this alloy are equal to those of the most expensive types, the material being practically unattacked at temperatures up to, or even exceeding, 1,050° C. In comparative trials this steel has, in fact, proved even more reliable than nickel-chromium alloys containing a high percentage of nickel, which showed a good deal of variation between different samples. In addition, it has been found to behave extremely well when exposed in furnaces where the atmosphere is sulphurous, as for example, in an oil-fired furnace. Under such conditions material of the type previously mentioned,



NOZZLES FOR HIGH PRESSURE GAS BURNERS.



Comparison of Results obtained from Furnace Racks made of Special Non-Scaling Steel and Mild Steel.



Comparison of Behaviour of Different Materials Exposed to Oxidising Conditions at High Temperatures.

although not failing badly, is seen to very much less advantage as compared with ordinary steel and certainly does not justify its enhanced price.

"Era" steel has already found numerous practical uses, it being possible to supply it either in the form of castings or forgings. When used for motor car and aeroplane engine valves, specially under conditions of high duty, as in racing cars, or air-cooled engines, it has given results unequalled by any other material.

A laboratory muffle and trays made of "Era" steel and used for over twelve months at a temperature of 900° C. show no signs of deterioration, whereas the fireclay muffles and trays formerly employed never lasted more than two months and, being fragile, were often broken sooner. Similarly in the case of certain high-pressure gas burners used in lighting the Westminster district of London, the nozzles made from gun metal were a continual source of trouble. After a period of only six to nine months they became not only inoperative owing to excessive heat-scaling, but were troublesome to remove for replacement by the screw threads having become oxidised. Nozzles of "Era" steel, as illustrated in Plate XLVI, have provided a welcome solution of this difficulty, and after two years service are showing no signs of deterioration.

In the upper part of Plate XLVII, there is shown a striking contrast between the behaviour of a furnace rack made from the special non-scaling steel and one made from cast mild steel. The racks were used in a spring-hardening furnace at a temperature of 900° C.; at the end of twelve weeks mild steel racks were so badly scaled as to be of no further use, the spaces between the teeth becoming choked with scale and, when this was removed, very little of the original teeth was left to enable them to perform their function as separators. Racks in this material, therefore, were continually being replaced and formed an appreciable item of expense. Racks of "Era" non-scaling steel which have succeeded them are still in excellent condition after fifteen months use, thus already showing a life at least five times as long, and from their present appearance they will last for a considerably longer period. Notwithstanding their higher initial cost, therefore, these racks are effecting a real economy besides facilitating the work by not calling for constant attention.

A particularly instructive comparison between the behaviours of different materials, when exposed to oxidising conditions at

high temperature, is afforded by the lower illustration on Plate XLVII. All the pieces shown were subjected simultaneously to the same treatment, viz.: exposed at 900° to 1,120° C. in an oxidising atmosphere for 54 hours.

The results of this drastic test are summarised in Table XI, from which the superiority of the " Era " steel is evident, the machined threads being sharp at the end of the exposure.

TABLE XI

DATA FROM SCALING TEST ON PIECES SHOWN IN PLATE XLVII

Material Reference letter in Plate XLVII	Mild Steel A	Nickel-Chromium Steel B	Non-rusting (stainless) chromium steel C	"Era" Steel D	"Era" Steel E	Mild Steel F
Original dia., inches	1·125	1·125	1·125	1·125	1·125	...
Dia. over scale, inches	1·22	1·152	1·10	1·138	1·138	...
Dia. after removing loose scale, inches	1·04	1·142	1·065	1·131	1·130	...
Thickness of loose scale, inches	0·18	0·01	0·035	0·007	0·008	...
Character of scale	Very loose	Very adherent	Comparatively loose	Very adherent	Very adherent	Rod oxidised nearly through

The great resistance to oxidation of " Era " steel up to 1,000 or even 1,100° C., combined with retention of its mechanical strength to a hitherto unequalled degree, renders it specially suitable for parts working under stress at high temperatures. It is well known that ordinary steels, specially when continuously loaded, are subjected to creep and ultimate breakage at very moderate temperatures, whereas the heat-resisting steels developed in the Hadfield Laboratories do not lose their ordinary properties and only undergo this transition to viscous creep at much higher ranges of temperature and stress. As

examples of their use may be mentioned the arms and fingers in gas producers which agitate the red-hot fuel, also the arms and racks employed in roasting furnaces handling sulphide ores. The valuable property mentioned, combined with immunity against scaling, enables them to be used for applications in which it has hitherto been necessary to employ water-cooling devices. One such application is the use of "Era" steel for Diesel engine valves in high-speed engines in which with the materials hitherto used water-cooling has been necessary to prevent their rapid deterioration. Valves of "Era" steel used without any method of cooling have been running for several months with complete satisfaction, no other steel having yet been found to stand up satisfactorily under such conditions.

As examples of applications where resistance to scaling is paramount, may be mentioned carbonising and annealing boxes, also pyrometer protection sheaths, the greatly increased life of which when made from these special steels altogether outweighs their extra first cost. In addition the freedom from alteration both in shape and thickness after considerable use confers further advantages in regularity of the products obtained. "Era" steel also greatly lengthens the life of lead pots and pyrometer protection tubes maintained in molten metal, e.g., aluminium. In furnace construction, too, the use of these steels proves valuable in the reduction of weight, specially in moving parts such as conveyor chains.

The foregoing does not, of course, exhaust the many interesting applications in which these special heat-resisting steels are finding employment. The success obtained in their use over a wide range of industries, although many of these applications are at present not completely out of the experimental stage, is such as to lead to the assumption that progress in many branches of engineering was being retarded for want of materials of this nature.

High-Speed Tool Steels.—High-speed steels derive their generic name from the fact that cutting tools made from these steels are capable of machining iron and steel at high speed. Under such conditions the tip of the cutting tool is generally at or near red heat. An essential requirement in a high-speed steel is therefore that the metal should retain its strength, toughness, and hardness at a high temperature. As a necessary corollary the steel must be self-hardening, *i.e.*, it must harden when cooled in air without quenching. Tungsten is particularly useful in so

lowering the transformation temperatures of steel that the latter becomes "self-hardening," and tungsten is consequently the alloying element present in greatest quantity in high-speed steels.

It is not too much to say that the introduction of high-speed tool steels has revolutionised machine-shop practice, and contributed to an essential degree in the evolution of present-day civilisation. Whereas cutting tools of ordinary carbon steel commence to soften at about 200° C., and are thus restricted to light cuts and moderate feed, high-speed steel retains its strength and hardness at red heat, and makes possible heavy cuts and rapid feed.

The first air-hardening tool steel, evolved empirically by Mushet about the year 1868, contained about 2·3 per cent. of carbon, 2·57 per cent. of manganese, 1·15 per cent. each of silicon and chromium, and 6·62 per cent. of tungsten. Steel of this type made possible about 50 per cent. higher cutting speeds than could be used with ordinary high carbon steel. The eminent American metallurgist, the late Mr. Maunsell White, found that by suitable heat-treatment the cutting power of the Mushet alloy could be greatly increased. His experiments led also to the discovery that a superior tool steel was obtained by increasing the percentages of tungsten to 15 per cent. or 20 per cent., which could be more easily worked than the original Mushet steel and was capable of about four times the cutting speed of the latter. In addition, chromium was substituted for manganese and the carbon content reduced. A typical high speed tool steel about twenty years ago, therefore, contained 0·6 per cent. of carbon, 0·12 per cent. of manganese, 0·05 per cent. of silicon, 3·44 per cent. of chromium, and 17·25 per cent. of tungsten. Innumerable high-speed tool steels have since been produced by different workers, some containing up to 2 per cent. of vanadium, up to 5 per cent. of cobalt, and a small percentage of molybdenum. According to the feed, cut, and quality of the material worked upon, cutting speeds from 250 to 500 ft. per min. have been made possible, resulting in from ten to twenty times the speed of machining attainable with carbon steel tools. As already mentioned, tungsten is the principal alloying element in modern high-speed steels, a typical analysis being: Carbon, 0·62 per cent.; manganese, 0·10 per cent.; silicon, 0·18 per cent.; chromium, 3·75 per cent.; tungsten, 16·5 per cent.; vanadium, 1·0 per cent. The inclusion of vanadium is found to increase

the durability of the tool under heavy working conditions, and to give an appreciable increase in cutting efficiency.

A very interesting high-speed alloy which contains no tungsten is "Stellite," invented by Elwood Haynes. This material, which can be heated to bright red or orange without softening, contains about 60 per cent. of cobalt, 22 per cent. of molybdenum, 11 per cent. of chromium, 2 per cent. of manganese, and only 3 per cent. of iron. Consisting as it does, almost entirely of non-ferrous metals, this material can hardly be called an alloy steel.

Steels for Armament and Ordnance.—Just as modern civilisation could not be carried on without the use of alloy steels, so warfare could not be conducted without them in the scientific manner and on the gigantic scale with which we are unhappily too familiar. War, with all its attendant horrors, is not to be counted amongst the blessings of civilisation; but in this instance, at any rate, some good has been derived from evil, because the development of alloy steels for the purposes of peace has been largely assisted by their application to war material.

Most of the largest single articles yet made in alloy steels have been produced in connection with war material, but composite products, such as tramway track layouts in manganese steel, built up from a number of separate parts, often exceed 100 tons.

Materials for armament and ordnance comprise mainly guns, projectiles, torpedoes, armour plating and gun-shields, bullet-proof plating for land service, and also the revival, during the late war, of body and head armour. In the latter application, manganese steel has proved particularly effective, as mentioned in Chapter VII.

At quite an early stage in the author's work upon the alloys of iron and chromium, some remarkable results were obtained with chromium-steel shell made by his firm.[1] A 6-in. projectile of this type was fired through a 9-in. compound plate. Being uninjured, it was ground up, fired a second time, and again penetrated uninjured another 9-in. compound plate. Needless to say, these encouraging results were a great incentive to further efforts; specially, too, as just previous to that time the British Government had found it necessary to procure certain supplies of armour-piercing projectiles from abroad. The results here

[1] See also "Alloys of Iron and Chromium," presented to the Iron and Steel Institute in 1892.

mentioned, however, showed that Great Britain was quite independent of foreign productions. Thus our Admiralty by its wise encouragement of home products has been able to obtain all its requirements from British manufacturers.

It is not possible to particularise with any freedom the various types of alloy steels used in the construction of modern armament and ordnance. In some cases secrecy has to be observed with regard to work of this nature carried out for the different Governments concerned. However, in the main it may be said that nickel-chromium steels containing not more than about 4 per cent. of nickel and 2 per cent. of chromium with, in some cases, certain modifications, have figured largely. The qualities of this type of alloy steel are well known and made use of in general engineering applications.

Nickel steels containing 5 per cent. or more nickel and 0·3 to 0·4 per cent. carbon are highly resistant to shock, and these alloys are used for the shield-plates of field-guns and for other purposes where resistance to impact is required.

Nickel-chromium steel, when suitably treated, develops hardness, toughness and strength which makes it useful for armour plates, but the possibilities in this direction have been surpassed by the nickel-chromium armour-piercing projectiles manufactured by the author's firm. These projectiles, in calibres up to 18 inches, are capable of passing undamaged through the thickest armour afloat, even with an oblique angle of incidence, and, indeed, have constantly done so in practice.

A modern 15-inch gun weighs 97 tons, has a length of 45 calibres, that is, 57 feet, and the projectile with its cap weighs 1,910 lbs. At its full elevation and with a muzzle velocity of 2,500 foot seconds, the range is 20 miles. Plate XLVIII represents photographs, probably the first ever obtained from a camera placed within 50 feet, of the impact of a large calibre projectile striking with more than 60,000 foot-tons of energy against a hard-faced modern armour plate.

The largest naval gun yet constructed is of 18 in. calibre—a calibre, by the way, which is now prohibited as a result of the Washington Conference. The gun weighs about 150 tons and, when elevated to 45 degrees, it hurls a projectile weighing 3,320 lbs. to a distance of 50,000 yards, or, roughly, 30 miles. Projectiles were made by the author's firm for this gun during the war, and it is found that the projectile, when capped and striking normally, is capable of perforating armour of the

Impact of 15-inch Armour-Piercing Projectile on Hard-Faced Armour.

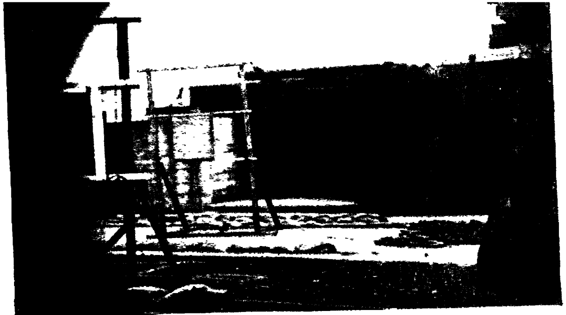


Fig. 1. View of Butt.

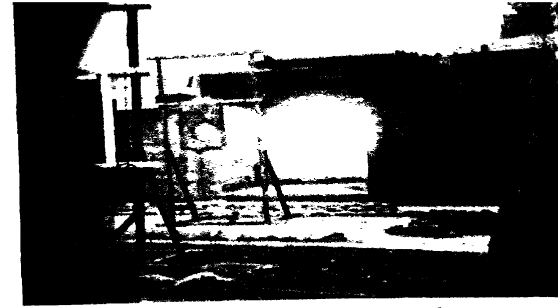


Fig. 2. One-Sixteenth Second Later. Impact on Plate.

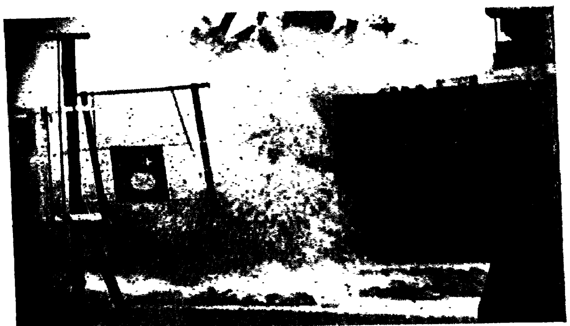


Fig. 3. One-Half Second Later; Note Flying Fragments from Butt.

Fig. 4. The Unbroken Projectile, weighing nearly one ton, after perforating the thick armour plate.

This plate represents three remarkable photographs showing the impact effect of one of the Hadfield Armour Piercing Projectiles, weighing nearly one ton, fired at high velocity against thick hard faced armour. Whilst the speed of the camera was too low to record the actual effect on the plate, it will be observed that the hole in the screen cardboard and the flash caused by the impact on the surface of the plate, all occurring in about one-seventieth part of a second, have been successfully obtained. It is probable that nothing of the same nature has ever before been shown, specially in view of the fact that the striking energy was very high, more than 60,000 foot tons. The fourth photograph shows the Hadfield large calibre projectile recovered unbroken and the hole which it has made in perforating successfully the thick hard-faced armour plate.

following thicknesses, the projectile itself remaining unbroken and carrying its bursting charge through the plate. At point-blank range a thickness of no less than 41 inches of hard-faced armour is perforated, which is equivalent to a wall of unhardened steel of about 4½ feet. At 10 miles and 20 miles respectively, 22 inches and 12½ inches of hard-faced armour of the latest and best type are perforated. Finally, at the extreme range of 30 miles, the projectile passes intact through nearly one foot of ordinary steel armour.

In actual trials projectiles from this gun have perforated hard-faced plates of a thickness nearly equal to the calibre of the gun, this too at an angle of 20°, and at a velocity equivalent to a range of about 9 miles. Thus the heaviest armour afloat, when attacked by an 18-in. gun, would not appear to be, metaphorically speaking, much better than cardboard.

The difficulty of hardening an armour-piercing projectile of these dimensions will be readily understood, for in the case of an 18-in. projectile a volume of something like 10,000 cubic inches of steel, heated to a temperature of about 900° C., has to be quenched suddenly in a cold bath of oil or other medium. The effect of this treatment is to convert material which has originally, when cold, a Brinell ball-hardness of only about 200, to one of hardness between 600 and 700. To deal with the strains set up by the sudden change from material which is almost plastic to one of the most extreme rigidity is indeed a difficult problem, as can be well imagined when it is stated that steel of this hardness readily scratches glass. In addition, it must be borne in mind that the rupture strains which are set up by the sudden cooling may continue, not for hours, but weeks afterwards. However, the problem has been solved satisfactorily and, amongst the tens of thousands of large calibre armour-piercing projectiles supplied by the author's firm for the use of our Navy, there is no record of a single one ever having been found cracked in store or on shipboard.

To give some idea of the extraordinary qualities of toughness combined with hardness possessed by the modern armour-piercing projectile, it will be interesting to mention the following example.

Not long ago a capped projectile of this type, made at the Hadfield Works, was returned unbroken after undergoing the following severe and most remarkable test. The thickness of the armour attacked obliquely, and therefore the more severe

test, through which this projectile had to pass, was about seventeen inches; its face was of the hardened type, having about 680 Brinell ball-hardness number, that is, of glass-scratching hardness, this hardness continuing to a depth of nearly two inches; the remaining portion was tempered down to the tenacity of a steel averaging a breaking strength of about 50 to 54 tons per square inch. The capped projectile in question fired at this plate travelled at the rate of over 1,600 feet per second, which is at the rate of approximately 20 miles per minute. It penetrated the hard face of the plate, also the remaining thick portion, but was not fired with sufficient energy to completely perforate the plate, so that, after firing, the base projected about five inches above the surface. The total length of the projectile was 46·15 inches.

Although having locked up in it no less than about 36,000 foot tons of energy, the projectile came to rest in the short space of only 40 inches! One can imagine the enormous stresses brought to bear on the projectile by the resistance of this solid wall of steel, that is, particularly on the ogival or front portion, yet the projectile remained unbroken and practically undamaged; indeed, a fine performance of a specimen of Sheffield steel.

Another comparison is the following:—This projectile, on striking the plate, had a similar energy—36,000 foot tons—to that of an express train composed of locomotive and five coaches weighing about 300 tons travelling at 60 miles per hour. The volumes of the two products referred to in this comparison are naturally quite different, that of the projectile being only 4 cubic feet, whereas the train would be about 11,000 cubic feet. Supposing the whole of the train mass to be moving along at the rate of 65 miles per hour, with a total energy of 36,000 foot tons, if the whole of it were, like the projectile suddenly brought to rest in the space of only three feet, and within one second of time, it is easy to conceive the terrible disaster which must follow.

A somewhat similar comparison—showing on the one hand the large amount of energy stored in a projectile in flight, and on the other the remarkable achievement of British engineering in an entirely different field—is obtained by comparing a small calibre armour-piercing projectile of 4½ inches diameter with the Rolls-Royce motor car shown in Plate XLIX. This particular example is chosen because the author has used the car illustrated

COMPARISON OF THE ENERGY OF A MODERN MOTOR CAR (ROLLS-ROYCE) WITH THAT OF AN ARMOUR PIERCING PROJECTILE.

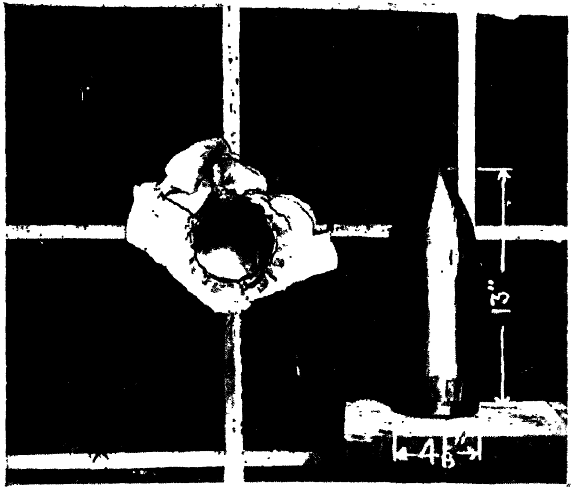


FIG. 1.

$4\frac{1}{8}$" PROJECTILE AFTER FIRING, AND THE 3" ARMOUR PLATE WHICH IT HAS PERFORATED.

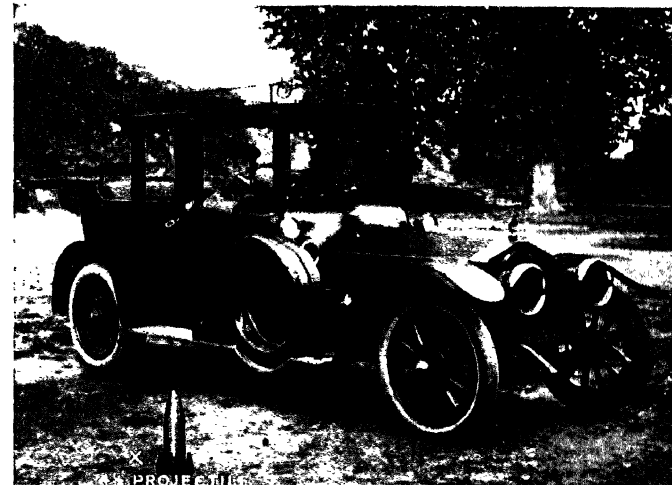


FIG. 2.

COMPARATIVE VIEW OF $4\frac{1}{8}$" PROJECTILE (BEFORE FIRING) WITH A ROLLS-ROYCE CAR.

THE SCALE OF FIG. 1 IS FOUR TIMES THAT OF FIG. 2.

$4\frac{1}{8}$" PROJECTILE.

WEIGHT	40-lbs. 6-oz.
VELOCITY	1100 FT. SECONDS.
	750 MILES PER HOUR.
ENERGY	338 FT. TONS.

MOTOR CAR.

WEIGHT	$2\frac{1}{4}$ TONS.
SPEED	60 MILES PER HOUR.
ENERGY	338 FT. TONS.

for more than ten years, without a single involuntary stop occasioned by any trouble on the engineering side of its construction. From time tables of runs with this car it is evident that a speed of 60 miles an hour is easily reached and maintained; indeed, on more than one occasion an average speed of about 40 miles an hour has been maintained, with unfavourable conditions of weather and road, from Boulogne to Beaulieu-sur-Mer—a distance of about 890 miles.

At a speed of say 60 miles per hour, the Rolls-Royce car possesses an energy of 338 foot tons. The $4\frac{1}{8}$ inch armour-piercing projectile, fired at 1,100 foot seconds velocity, leaves the gun in possession of the same energy, namely, 338 foot tons. With this energy the projectile in question perforates unbroken a hard-faced armour plate 3 inches in thickness, placed 100 feet from the gun. The motor car has a bulk of about 450 cubic feet as compared with 0·082 cubic feet for the projectile, yet this object with its small mass has stored in it as much energy as the large motor car travelling at 60 miles per hour.

This comparison, rather a curiosity of its kind, may be of general interest in that it illustrates some of the properties of the materials concerned, and gives a more definite idea of the amounts of energy carried by projectiles. It is indeed remarkable that an 18-inch projectile can expend 36,000 foot-tons of energy—more than a hundred times that contained by the $4\frac{1}{8}$-inch projectile in the preceding example—upon an armour plate of the highest quality, penetrating the latter but itself remaining unbroken.

In addition to offensive and defensive material, modern warfare involves a large amount of purely engineering construction, including the structure and machinery of warships, apart from special scientific instruments and appliances which call for the use of alloy steels just as does the engineering practice of peace.

Steels for Permanent Magnets.—Though magnets of permanent type do not owe their existence to the introduction of alloy steels, quite good magnets having been made from high carbon steel, and even the natural lodestone having its merits, the use of tungsten steels, and more recently steels containing cobalt, has greatly improved their qualities both as regards actual strength and permanency.

Formerly, permanent magnets were almost invariably made from high carbon steel containing 1 to 1·5 per cent. of carbon,

but during the past fifteen years or so some thousands of tons of tungsten steel have been used annually for this purpose. Madame Curie has made extensive investigations concerning the magnetic properties of tungsten steels, and has shown that a steel containing 5 or 6 per cent. of tungsten and 0·6 per cent. of carbon is particularly suitable for permanent magnets. The rather expensive nature of such an alloy stimulated research for a cheaper substitute and, while nothing quite so good was obtained, it was found that chromium steels approached the characteristics of the tungsten steel.

In 1909, Professor Brown, of Dublin, examined a range of steels made by the author's firm containing from 0·75 to 9·5 per cent. of chromium. From these investigations it was found that a steel containing 0·86 per cent. of carbon and 1·95 per cent. of chromium gave best results. The coercive force was fairly high, but chromium steel permanent magnets are less satisfactory than those of tungsten steel and much inferior to those of cobalt steel.

Following some years later the discovery of Professor Weiss, of Zurich, that the addition of 33 per cent. of cobalt to pure iron rendered it capable of taking up magnetism, under a sufficiently strong applied magnetising force, to an amount 10 or 15 per cent. greater than pure iron itself, there came the discovery by Professor Honda, of Japan, of a greatly improved permanent magnet steel in which this percentage of cobalt was used. It was to Professor Honda that the high distinction of the Bessemer Gold Medal of the Iron and Steel Institute was awarded in 1922.

The addition of hardening elements, such as chromium and tungsten, was also a feature of this permanent magnet steel. While possessing, in practical forms, similar magnetic strength to existing tungsten steel magnets, the force necessary to demagnetise this steel reached 220 units compared with about 70 for tungsten steel.

The high percentage of cobalt necessarily renders this alloy very expensive and restricts the field of its commercial applicability, but the material has found uses for special purposes, where performance is the primary consideration and cost is of minor importance. Apart from this, however, the discovery of this alloy is valuable as another indication of the practically unlimited possibilities of alloy steels in meeting engineering requirements of all kinds. Notwithstanding the amount of

research work which has already been accomplished, very little can be predicted as to the qualities obtainable from stated but untried compositions.

The cobalt steel called " Permanite " has been found superior to tungsten steel as a material for the permanent magnets of magnetos and other apparatus subject to powerful demagnetising influences. Its coercive force is 120, compared with about 75 for tungsten steel and 50 for carbon steel, whilst the remanent magnetism exceeds 11,000 c.g.s. units compared with about 10,000 for tungsten and 8,500 for carbon steel.

Steels of High Permeability.—Steels which require the least possible magnetising force to magnetise them, are of great importance in electrical industries. In general, the magnetisation is produced by the action of electric currents, so that the larger the magnetising current required the greater is the amount of copper required to carry it; the first cost is thus increased and, as a result of the higher ohmic losses, the efficiency is reduced and the running expenses are increased. Wherever alternating or fluctuating currents are concerned the use of material of low magnetic permeability results also in larger dissipation of energy in continual magnetisation and demagnetisation, for, so far as research has gone at present, it seems to be the general rule that easily magnetised materials, that is, those of high permeability, are also subject to the lowest hysteresis loss.

The degree of magnetisation which steel receives in various practical applications varies from the very minute fields operating, for example, in loaded telegraph and telephone cables, to practically saturation, as in the armature teeth of certain dynamo-electric machines. It is a curious fact that no one material is best over the whole range of magnetisations. In the range of medium intensities of magnetisation, which are employed in most of the work connected with electric-power generation, distribution, and application—and are thus, in the aggregate, of greatest industrial importance—the outstanding contribution of alloy steels still remains the author's silicon steel, which is described fully in Chapter VIII.

At saturation intensities, another and quite different type of alloy which has already been mentioned—namely, the alloy of iron and cobalt, containing 33 per cent. of cobalt, discovered by Professor Weiss—has the highest permeability of any known material, exceeding even that of pure iron by 10 to 15 per cent. This material, however, has not found any extensive

practical application, probably owing to its expensive nature, as the quantities involved would be very considerable.

Special Magnetic Properties.—In regard to their magnetic properties, the nickel steels show wide variations and many peculiarities. Much work has been done in this difficult field by Hopkinson, Barrett, Ewing, Osmond, Guillaume, Dumas, the author, and others. Without attempting a detailed survey of the results obtained, some of the more striking phenomena may be mentioned. Steel containing 25 per cent. of nickel is non-magnetic in its ordinary condition, but if cooled to – 40° C. it becomes magnetic and has then to be heated to nearly 600° C. before it regains its non-magnetic properties. For applications requiring a non-magnetic steel, and where the difficulty of machining manganese steel is a disadvantage, nickel steel containing 25 per cent. of nickel forms a useful alternative.

Perhaps the most extraordinary of all nickel-iron alloys is "Permalloy"—containing about 78 per cent. nickel and 22 per cent. iron—which, after suitable heat-treatment, has such a remarkably high permeability at low inductions that it approaches saturation in the earth's field. The initial permeability of "Permalloy" at zero field, as determined by extrapolation, is many times greater than that of the best soft iron, and it is for this reason that the saturation value (about 11,000 gauss, comparable with that of iron) is approached with the weak magnetising force of the earth's field. This remarkable material, which can, perhaps, in view of the predominance of its nickel content, hardly be claimed as an alloy steel, was discovered in the laboratories of the Western Electric Co. of America, and it is of the highest importance in those applications involving very low magnetisations, particularly the loading of telegraph and telephone cables.

In a paper at the World Power Conference, in 1924, on "New Fields of Research for Power Development," Mr. E. W. Rice, Jun., of the General Electric Co. (Schenectady), announced the appearance of still another new magnetic alloy containing nickel and iron in equal proportions, the special characteristic of which is an extremely low magnetising loss amounting to only 0·40 watt per lb. at 60 cycles, with an induction density of 10,000 lines per sq. in. It is not stated what are the practical applications for this alloy, but such a desirable quality cannot fail to find application.

Apart from the actual effects of alloying, the metallurgical processes to which a material is subjected have a great influence on its magnetic qualities. Yensen has found, for instance, that melting *in vacuo* has a profound and favourable effect on the quality of many magnetic materials.

With the examples which have been cited in this chapter before us—and many more might have been mentioned but for the limitations of space—it cannot be doubted that the metallurgist will continue to keep pace with the requirements of industry and, in many instances, bring about advances by providing new materials of improved quality.

PART III—FUEL ECONOMY.

CHAPTER XI

FUEL ECONOMY.

The leading characteristics of various fuels, and methods of controlling their combustion as regards temperature and efficiency, are matters of considerable importance to metallurgists, for large amounts of heat are required in the manufacture of iron and steel, including alloy steels, and accurate control of temperature is essential in all processes from the reduction of the ore to the heat-treatment of the final product. To a great extent, economy in operation and accuracy in control and application can be attained by the same means, where the combustion of fuels is concerned, for both depend ultimately upon measurements of heat and temperature. In preparing the following notes upon these and associated problems, the author has received valuable assistance from Mr. R. J. Sarjant, M.Sc., who is in charge of the Fuel Department of his Company's works.

In his Presidential Address delivered to the Society of British Gas Industries in 1918, the author dealt very fully with Fuel, Fuel Research, Coal, Oil, Peat, Future Sources of Energy; then as regards Gas, the Growth of the Gas Industry, the Action of Gas Flames in Furnaces, the Composition of Gases and "Mixture" Heat Values, and the Calorific Value of Various Gases. This Address proved for some time to be quite a standard work of record on the above subjects, and its many readers were kind enough to say that the information and data there presented were most useful.

Factors Influencing Fuel Economy.—The principal factors which determine the efficiency and economy of any fuel-burning apparatus are:

(1) The nature of the fuel, i.e., whether it is suitable for the purpose.

(2) The conditions of combustion.

(3) The efficiency with which heat is absorbed from the products of combustion.

Such questions as the relative merits of fuels from different sources of supply, of different grades, or even of different kinds, are determined by purely commercial considerations if, *and only if*, the alternative fuels are equally capable of rendering the heating service desired. In determining whether a particular fuel produces the heat desired, and in investigating the conditions of combustion and the efficiency of heat absorption, temperature measurements are specially important. The chemical composition of the raw fuel, and the possibility of recovering by-products in the gasification process are also important problems. The measurement of temperatures is one of the simplest and most effective methods of investigation and control available to the use of any fuel-consuming plant. The taking of gas-analyses is also a useful aid.

In a paper on "Fuel Economy and the Measurement of High Temperatures" presented to the first World Power Conference in 1924, the author reviewed the part played by temperature measurement in relation to fuel economy. Although some of the information there given applies more particularly to plant for the manufacture and heat treatment of steel, it should also be of interest to power engineers, for the principles of fuel economy are not restricted in their application.

In the following pages some information is given concerning fields in which pyrometry has enabled accurate heat balances—and hence economy of fuel—to be attained. Such a survey, within the space here available, must necessarily be confined largely to generalisations based on a wide practical experience as to the nature of the problems encountered in studying the fuel economy of the appliances mentioned, and as to the methods by which they may be attacked.

Characteristics of Fuels.—Some of the principal attributes determining the suitability of fuels for various applications are the calorific value, the constitution of the fuel, and the flame temperature produced. An accurate knowledge of the thermal values of fuels on a cost basis is also important and, in this respect, Table XII is interesting. From this it is evident that some fuels have a great initial advantage under prevailing market conditions. The last column of air values in this table is given with the object of showing what volumes of air are necessary to produce the same quantity of heat from different fuels, for we have to debit against the fuel this waster

of heat units in cases in which the air control is not closely watched.

TABLE XII

COMPARATIVE FUEL VALUES.

Fuel.	Calorific Value B.Th.U. Gross.	Cost, May 1925.	Thousand B.Th.U. per 1d. cost.	Bulk.	Theoretic Volume of Air for Liberation of 1000 B.Th.U Cu. ft. at 15° C.
	Per Lb.	Per Ton.		Cu. Ft.	
Coal.		s. d.		Per Ton.	
Anthracite (Welsh)	15,000	50 0	56·0	40	10·1
Bituminous hards (Yorks, Derby, and Nottingham coal-fields)	12,250	24 6	93·2	48	11·0
Bituminous nuts (ditto)	12,250	22 0	104·5	45	11·0
Coke.					
Foundry coke	13,500	48 0	52·4	65	10·3
Steel melting coke	13,200	33 6	73·6	70	10·5
Large gas coke	12,900	24 8	70·0	80	10·45
Breeze coke	12,800	33 0	72·0	58	10·5
Liquid Fuel.		Per Gal.			
Petrol	20,000	1 5	8·5	25·9	9·85
Benzol	17,750	1 0	13·1	31·8	9·85
Paraffin	19,950	10	16·35	29·7	9·45
Heavy oil (blast-furnace neutral fuel oil)	16,000	4½	35·1	33·4	10·3
	Per Cu. Ft.	Per 1000 Cu. Ft.*		Density Relative to Air.	
Gas.					
Town's Gas	535	1 10	25	0·61	8·3
Water Gas	310	8·4	37	0·53	7·1
Producer Gas	165	3½	47	0·86	7·6

* In a discussion in 1918 before the Engineers' Society of Western Pennsylvania, Mr. A. E. Blake gave an estimate of the cost of blue water-gas and producer-gas, based on prices prevailing in America. For large sets he quoted the price per million B.Th.U. produced as 28·91 cents for water-gas made in sets provided with waste-heat boilers, and 27·35 cents for producer-gas. These figures correspond to a production of 79·1 and 85·6 thousand B.Th.U. per 1d. for the prices and rate of exchange obtaining at that time.

When the calorific value of a fuel is determined by the usual calorimetric methods the gross value is usually taken, as the determination of the net value involves more complicated analysis—the estimation of the hydrogen. It is often found, however, that the usefulness of a fuel, other things being equal, is not *pro rata* with its heating value as thus determined. This is especially so in the case of furnaces. The author has observed instances where a fuel has given superior results far in advance of any improvement in calorific value. The factors involved are dominantly the clinkering and caking properties of the fuel in the cases of solid fuel, which determine the rate and completeness of its combustion.

Damour * has dealt with this subject and suggested that an "utility value" be determined for each fuel by reason of the

(*) "Le Chauffage Industriel et les Fours à gaz."

variable conditions of combustion and operation inherent in furnace practice. He makes the plant itself virtually the calorimeter, and measures the consumption of fuel giving the same production and thermal effect in a given furnace. Presumably the principle applies also in the generation of power. There is much to be said for this method from the practical standpoint. It involves particular attention to those aspects of the heat balance on which we are attempting to focus attention. It gives a direct index of the combustibility and suitability of the fuel, and evaluates a factor not readily estimated by any other method. However, it also involves a knowledge of temperatures of combustion, a subject about which all too little is known.

In recent years much more attention has been given to the constitution of the fuel itself, and whilst the incentive to this study has been the need for improved methods of the carbonisation of coal the knowledge gained has an important bearing on our problem. The behaviour of the macro-constituents themselves on being heated determines the burning properties of the fuel, and if more attention were devoted to this aspect of the subject, the question of the selection of fuel for specific purposes would become a much more simple matter. A simple coking test on the fuel tells one much as to the probable behaviour of a coal in a furnace.

The determination of the volatile matter has long been regarded as a test almost as important as that of the ash and moisture, and more recently the relative values of the fixed carbon, the volatile matter and hygroscopic moisture have entered into the bases of classification. Reference is made rather to an inspection of the physical character of the coke produced, considered in conjunction with the quantitative data.

The characteristics of " swift," caking, non-caking or neutral fuels all have their explanation in the nature of the various macro-constituents of the fuel. There are questions of size which also determine the resistance of the fuel bed, but this is controllable by its thickness.

As regards flame temperatures, until there are accepted means of determining the true calorific intensities of fuels it is necessary to judge of these values by taking the ratio of the total available heat of combustion of the fuel to the heat capacity of the products of combustion. That this figure is much in advance of the true flame temperature is well known.

The experimental attempts to measure flame temperatures have been necessarily confined to laboratory experiments in which the conditions of works practice are not entirely reproducible. The temperature as given by an optical pyrometer will depend on the thickness and density of the flame as well as upon its reflecting and absorbing powers.

An approximate method for determining the true flame temperature based on the experiments of von Helmholz on the radiation from flame has been demonstrated by Bone.* The values of relative calorific intensities of gas-air flames thus determined fell within the same range as the experimental determinations of Féry and others.† However, Féry found values for the Bunsen flames of coal gas varying from 1710° to 1870° for various air adjustments. In a small experimental furnace at the author's laboratories there has been obtained a temperature of 1800° with Sheffield city gas, and even as high as 1700° by the single use of a blast burner of his own design coupled directly to the low pressure gas supply, the realisable calorific intensity depending upon the manner of mixing the gas and air.

Selection of Fuel.—Different fuels have more or less distinctive characteristics which render them inherently suitable or unsuitable, as the case may be, for particular applications. Some of these advantages and disadvantages are summarised usefully in Table XIII, for which the author is indebted to Mr. Robert E. Dillon of the Edison Electric Illuminating Company, Boston (Mass.). The statement made in this table that electricity as a heating agent offers every advantage save that of low price needs, perhaps, a little amplification. For some purposes the advantages of electric heating—in point of cleanliness, accuracy of control, and/or the high temperatures which can be reached—make the question of price quite a secondary consideration. In other cases, however, such as the smelting of ores, the heating of billets, and the raising of steam, electricity is generally much too expensive to be used.

In this connection it may be interesting to recall that Sir Arthur Duckham said, some time ago, that it seemed to him that lighting would form the least important part of the supply of either gas or electricity. Household lighting would more

* "Coal and its Scientific Uses," Page 260.

† "Measurement of High Temperature," Burgess and Le Chatelier, Pages 338, 485.

TABLE XIII. GENERAL ADVANTAGES AND DISADVANTAGES OF VARIOUS FUELS.

FUEL.	ADVANTAGES.	DISADVANTAGES.
WOOD .	(a) Cleanliness. (b) Cheerful fire. (c) Quick increase of heat. (d) Cheap in some localities.	(a) Low fuel value. (b) Large storage space necessary. (c) Labour in preparation. (d) Scarcity. (e) Does not hold fire long. (f) Unsteady heat.
PEAT . .	(a) In general the same as wood.	(a) Low heat value. (b) Bulkiness.
Anthracite .	(a) Cleanliness. (b) Easy control of fire. (c) Easier to realise heat in coal than is the case with other coals. (d) Steady heat.	(a) Price high. (b) Difficulty of obtaining. (c) Slower response to change of draughts.
BITUMINOUS COAL .	(a) Low price. (b) Availability (c) High heat value (in the best grades). (d) Low percentage of inert matters (in the best grades).	(a) Dirty. (b) Smoke produced. (c) More attention to fire and furnace necessary than with anthracite.
SUB - BITUMINOUS COAL AND LIGNITE. .	(a) Relatively low price. (b) Availability (in some regions). (c) Responds quickly to opening of draughts.	(a) Slakes and deteriorates on exposure to air. (b) Takes fire spontaneously in piles. (c) Heat values generally low. (d) Heat in fuel difficult to realise. (e) Fires do not keep well. (f) Gases generated over fire-box sometimes burn in smoke pipe, causing excessive heating.
COKE . .	(a) Cleanliness. (b) Responds quickly to opening of draughts. (c) Fairly high heat value.	(a) Bulkiness. (b) Liability of fire going out if not properly handled. (c) Fire requires rather frequent attention unless fire-box is deep.
OIL . .	(a) High heat value. (b) Immediate increase of heat. (c) Cleanliness. (d) Small storage space necessary.	(a) High price. (b) Difficulty of safe storage.
GAS . .	(a) Ease of control. (b) Cleanliness. (c) Convenience. (d) Immediate increase of heat.	(a) High price in many places.
ELECTRICITY	(a) Every advantage.	(a) High price.

and more turn to electricity as the price was reduced, but power essentially would be the sphere of electricity, and heating the sphere of gas. Solid fuel should be as far as possible eliminated, thus saving dirt, road transport, etc. The time having come when electrical development in this country was being discussed, Sir Arthur added that this time should not be allowed to pass without strenuous efforts being made to combine the interests of gas and electrical undertakings in order that the greatest use might be made of the coal which forms the basis of all light, heat and power supplies. In this opinion the author concurs.

As matters stand at present, the choice of fuel for any particular heating service is largely governed by local conditions of supply. By suitable adjustment of combustion chamber dimensions to those of furnace chamber, practically any fuel may be applied to any given furnace problem, but, for best economy, the furnace conditions must be adjusted to make use of the highest calorific intensity the fuel is capable of giving.

Certain fuels, however, lend themselves most suitably to certain operations, and should therefore be used if possible. Thus, highly volatile coals of a non-caking character are particularly adaptable to direct firing in short period intermittent furnaces. There are certain seams of coal in the Notts and Derby coalfields which provide excellent producer coals, by reason of the fact that whilst they are sufficiently non-caking to eliminate channelling, they yield a coke of sufficient strength and porosity to ensure an even distribution of the blast in the fuel bed. The use of powdered fuel for the high intensity work of the cement kiln found its application long ago in this country, whereas its development for the lower temperature requirements of the forge and heat treatment furnace has hitherto been slow. The use of oil and town's gas for the smaller type of furnace has become established, whilst producer gas will continue to hold its own for those larger furnaces of the continuous type which justify the use of the recuperator or regenerator.

The Action of Flame in Furnaces.—Much light has been thrown on this important subject by the researches of Professor W. E. Groume-Grjimailo, Professor of Metallurgy at the Polytechnic Institute of Petrograd, who conceived the idea that any furnace might be regarded as a reservoir, so that the design of furnaces and flues became a problem in hydro-dynamics.

The circulation of flame and hot gases may, in fact, be likened to the movement of a light liquid within a heavier one.

The general principles arising from Professor Groume-Grjimailo's work and their bearing upon furnace design may be summarised as follows, these matters being dealt with most ably in a paper delivered some years ago by Mr. A. D. Williams to the Cleveland Engineering Society (Ohio). Recently his work has been translated by Mr. Williams and is available in book form.*

Planes of Separation.—It is claimed that hot gases in the furnace tend to circulate according to the following analogy in nature, namely : A river which flows in its bed is supported by the earth and bounded upon its sides by the natural surface of the ground. Its upper surface is separated from the air by a horizontal plane whose position is not fixed, but which varies with the quantity of water flowing into the stream. The hot gases in a furnace tend to circulate in exactly the same fashion, with this difference, that the plane of separation from the air is below, and the cross-section of the bed is formed by the roof and walls of the furnace. Nevertheless, we frequently consider that the flame fills the furnace and heats it uniformly, when in reality it circulates in the upper portion only, and does not come in contact with the material placed on the hearth. The utilisation of the heat is very inefficient. The stream of flame flows along the roof and carries all of its heat to the chimney.

Furnace Arches Rarely Effective.—Our error lies in neglecting the part which the ocean of air plays, and it is due to this that we have difficulty in comprehending the circulation of the flame in the furnace. But when we commence to take account of the air, then the question of flame circulation becomes very clear.

What is a flame ? It is a mixture of gases at a sufficiently high temperature to permit of their entering into the reaction called combustion, thus releasing sufficient heat to raise the products of combustion to incandescence.

Exposition of Theory.—We may consider a reverberatory furnace as an apparatus immersed in a liquid—the air—while in the interior of the furnace a current of incandescent gas circulates—that is to say, a lighter liquid.

* There is also a French translation *Fours à Flammes*, by L. Douglatch and A. Rothstein. Dunod et Pinat, Paris, 1914.

Some idea with regard to the difference in the density of air at the temperature of an open-hearth furnace, about 1650° C., and air at 0° C., may be obtained by comparing the high temperature air to water, and the low-temperature air to molten iron, the weight of water being 1,000 kilograms per cubic metre, whilst the weight of molten iron is 6,900 kilograms per cubic metre.

A furnace in operation may therefore be considered as immersed in an aquarium containing a heavy liquid, while its interior is traversed by a lighter liquid, and all of the movement of the flame may be compared to that of the light liquid as it floats in the heavier liquid.

Observation through Model.—A model has been built at the Petrograd Polytechnic Institute to reproduce practical working conditions. The open sides of this model are closed with pieces of glass. Tube connections are arranged to the various ports and the chimney opening. This model is then immersed in a glass tank filled with water and coloured petroleum is circulated through it. The various tubes are supplied with regulating valves. The highest bottle is filled with coloured petroleum, and is elevated to give it an initial head. A drain is provided by which the petroleum, as it rises to the top of the water, flows into the lower bottle, from which it is returned to the upper bottle by means of a small pump driven by an electric motor, so that continuous circulation may be maintained.

Upon starting the circulation of the coloured petroleum, it rises from the fire-boxes in a thin stream, ascending the arch of the kiln and escaping at the central vent.

Hydro-dynamic Formulæ.—For design purposes furnaces may be placed in five classes, as follows :

(1) Small, direct-fired furnaces, in which the gases remain only a fraction of a second. The material is charged cold, and the combustion depends upon cold air, the fuel-bed being thin. The furnace under a steam boiler is an example of this type.

(2) Direct-fired furnaces, with arch over grate, thick fuel bed. Natural or forced draught, rapid combustion, can be worked with 50% excess air. Furnaces included in this type are reverberatory, matting, and heating furnaces, puddling furnaces, glass furnaces, re-heating furnaces.

(3) Furnaces fired by producer gas, with 150% to 170% of the theoretical air supply. Most gas-fired, re-heating furnaces fall in this class.

(4) Open-hearth and similar furnaces, gas-fired where the secondary air supply is 125% to 150% of the theoretical.

(5) Furnaces fired with theoretical air supply or slight excess of air, in which the gases travel slowly. Some brick-kilns, tempering furnaces, and re-heating furnaces come under this class. Furnaces may be gas-fired or form a continuation of the gas producer.

Time of Combustion.—An important factor is the length of time the gases remain in the furnace. This is governed by the temperature at which the gases leave the hearth and the flame temperature; in other words, the temperature drop per second. This drop is as follows:

	°C. per second.
(*a*) Open-hearth furnaces	200
(*b*) Re-heating furnaces, gradual	150 to 200
(*c*) Re-heating furnaces	100 to 150
(*d*) Brick-kilns	80

These values have not been finally established. Exact data can only be obtained from observations upon correctly constructed furnaces.

Temperature Drop.—The fall in temperature per second is a function of:

(*a*) The radiation loss. This is peculiar to each type of furnace, and depends upon the nature and area of the radiating surface, the thermal conductivity of the walls, and the flame temperature.

(*b*) The heat absorption capacity of the material heated. A furnace charged with hot metal or ingots works differently from one charged with cold material. The drop in temperature per second will be higher in the second furnace than in the first.

Finally, it is stated that, knowing the working conditions of the furnace to be designed, the procedure is as follows:

(*a*) The volume of the heating chamber is calculated.

(*b*) The volume of gas obtained per kilogram of coal burned under the service conditions is computed.

(*c*) The theoretical combustion temperature of the fuel with an assumed excess of air is computed.

(*d*) The temperature, in degrees Centigrade, at which the waste gases are to leave the heating chamber is determined. This is approximately as follows:

		°C.
(1)	Open-hearth furnaces	1,600
(2)	Puddling and melting furnaces, reverberatory	1,250
(3)	Soaking-pit furnace	850
(4)	Heating furnaces	1,000
(5)	Glass-melting furnaces	1,200

(*e*) Knowing the temperature of the flame and the temperature of the waste gases, the total temperature drop in the furnace is established. This, divided by the drop in temperature per second, gives the time the gas should remain in the heating chamber.

(*f*) The capacity of the heating chamber, divided by the time the gases remain in it, gives the volume of gas per second Q_t at the average temperature of the furnace. From this the quantity of gas at 0°C. equal to Q_o is established, and from this the weight of fuel burned per second and per 24 hours can be arrived at.

(*g*) Knowing Q_t, the principal dimensions of the furnace may be computed. The velocities of the gases in different parts of the furnace are calculated, and from this the necessary hydrostatic head required to supply this velocity can be arrived at. This determines the height from the bottom of the grate to the sole of the furnace for natural draught, or the blower pressure required. The height of the chimney and the sizes of various flues can also be computed.

It should be added that these methods of computing furnaces are still in a controversial stage since they have not been undeniably demonstrated to hold for all classes of heating. Groume-Grjimailo did not take into account the important influence of radiation, nor is it possible by such means to take into account the influence of turbulence in gaseous flow. Heat transmission factors largely enter into any furnace computation, so that the temperature drop, assumed by Groume-Grjimailo to be fairly constant for certain classes of furnaces, actually varies considerably.

However, as a further indication of the importance of Professor Groume-Grjimailo's work it may be mentioned that the author's friend, Professor Henri le Chatelier, who has investigated this question, says : " He brings forward a principle relative to the circulation of the hot gases in a furnace—a very simple principle, but one which has not been thought of before.

We think of gases as filling completely, by reason of their absolute elasticity, the vessels which enclose them. And by unconscious induction, but inexactly, we conclude that gases, in their circulation traversing a series of enclosures, traverse equally all points of the spaces open to them and sweep uniformly, by their current, all the passages through which they pass. Perhaps we should not formulate this erroneous principle in such a precise manner, but, nevertheless, we act as if we believed firmly in it. And it follows, in the construction of furnaces, that very grave errors are made, to which Professor Groume-Grjimailo calls our attention by numerous examples."

Determination and Control of Calorific Intensity.—The obtaining of economical combustion depends primarily upon correct appreciation and control of flame conditions. As an example of the economies which may be effected in this way, reference may be made to the regenerative furnace largely due to Martin, the famous French metallurgist, whose work was followed up in this country by the late Sir William Siemens. Another example is obtained by comparing the ordinary Bunsen gas burner with the Meker burner. In the latter, by better arrangement of the apparatus, much higher temperatures are obtained, namely, a maximum of 1720° compared with 1560° C. from the ordinary Bunsen burner.

In dealing with the subject of gaseous fuel, in his Presidential Address to the Society of British Gas Industries in 1918, the author drew attention to its economic utilisation in industrial heating, and to stimulate investigation and interest in the subject offered a prize for the best essay on the use of gas in commercial practice. In the prize essay, which was adjudicated on by the Society of British Gas Industries,* Mr. F. W. Epworth stated that "much waste in the use of gaseous fuel . . . arises largely from lack of knowledge of the principles involved," and made one of the objects of his paper to set out the underlying principles which govern its control. Not the least useful of the information he gave was a series of calculations of waste heat values and theoretical calorific intensities of some typical gaseous fuels. Indeed it was a step in that compilation of data which is needed, but fell short of its best utility in not being presented in graphical form.

In order that the value of such work might not be over-

* Published in the *Gas Journal*, June 17 and 24, 1919.

looked the author and Mr. R. J. Sarjant, M.Sc., in a joint paper on "Fuel Control in Metallurgical Furnaces" presented to the Autumn Meeting of the Iron and Steel Institute in 1919, gave a graphical chart, Plate L, based on some of Mr. Epworth's tables, showing the effect of excess air and temperatures of regeneration on the calorific intensities of three typical gases of the compositions shown in Table XIV.

TABLE XIV. COMPOSITION AND CALORIFIC VALUE OF TYPICAL GASES.

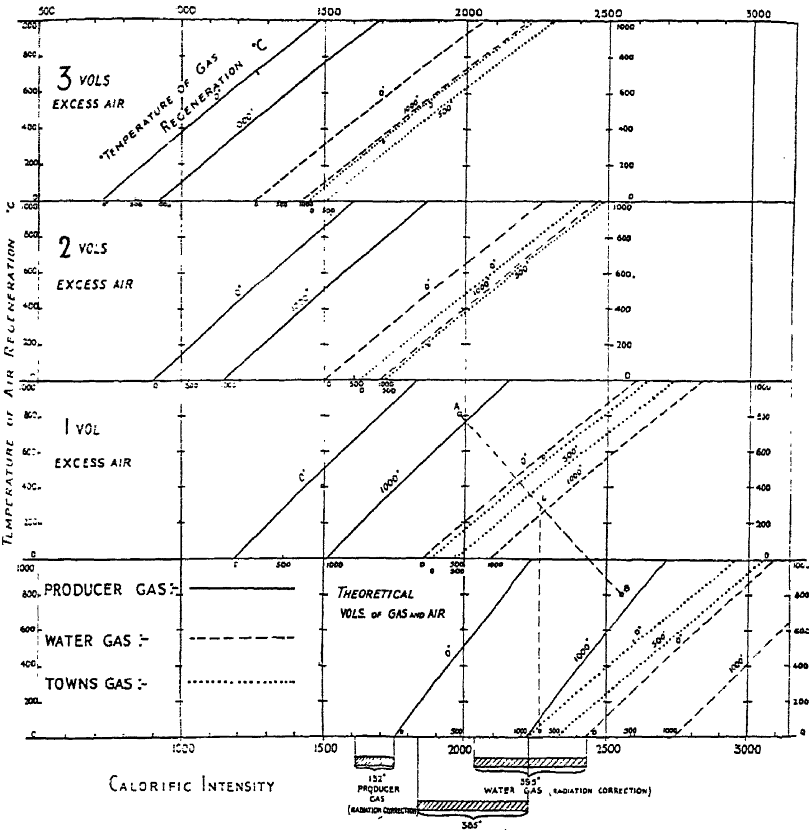
Gas.	Percentage Composition by Volume.						Calorific Value. B.Th.U. per Cu. Ft. at N.T.P.		B.Th.U. per Cu.Ft. Mixture for Theoretical Combustion.	
	CO	CO_2	C_nH_m (i)	C_nH_{2n+2} (ii)	H_2	N_2	Gross.	Net.	Gross.	Net.
Producer-gas	23·0	4·0	..	2·2	14·0	56·8	151	141	68·5	64·1
Water-gas .	42·0	4·0	..	0·5	51·0	2·5	326	299	99·0	90·7
Town's gas.	17·0	3·0	3·0	24·0	41·0	12·0	509	459	98·9	89·2

(i.) Taken as C_2H_4. (ii.) Taken as CH_4.

Consideration of this abstract notion of "theoretical calorific intensity," or the ratio of the net available heat to the thermal capacity of the combustion products, must be made with certain reservations, or it becomes deceptive and likely to lead to false conceptions of the heating effect of different gases.* Before it is possible to draw up a similar chart of true calorific intensities much fundamental research work needs to be done. A complete quantitative investigation of the thermal equilibria involved in the process of combustion is attended with considerable difficulties and opens up a wide field of endeavour, in which our own scientific men have not been inactive, its exploration dating from the time of Deville (1863). With proper regard being paid to its shortcomings, the presentation of such data has its uses from an instructive point of view and in stimulating interest in its present deficiencies.

With regard to the disturbing factors, Professor W. A. Bone†, at the Autumn Meeting of the Iron and Steel Institute, in Brussels in 1913, drew attention to the question of radiation from flame, and a very clear account of the subject is given

* W. A Bone, "Coal and its Scientific Uses." (Longmans).
† *Journal of the Iron and Steel Institute,* 1913, No. II., p. 111.



EFFECT OF EXCESS AIR AND TEMPERATURES OF REGENERATION UPON CALORIFIC INTENSITIES OF THREE TYPICAL FUEL GASES.

EXPLANATORY NOTES.

The theoretical value for calorific intensity can be obtained by double interpolation.

EXAMPLE : *Required the value for producer gas when*

(I) *Temperature of gas regenerrtion* = 900°.
(II) „ „ *air* „ = 800°.
(III) *Excess air* = 50%.

METHOD : (I) *In section for 1 volume excess air interpolate on 800° air abscissa for gas regeneration temperature of 900°. So obtain point A.*
(II) *Repeat in section for theoretical volumes for gas and air. So obtain point B.*
(III) *Interpolate between A and B for 50% excess air. Thus obtain C = 2265.*

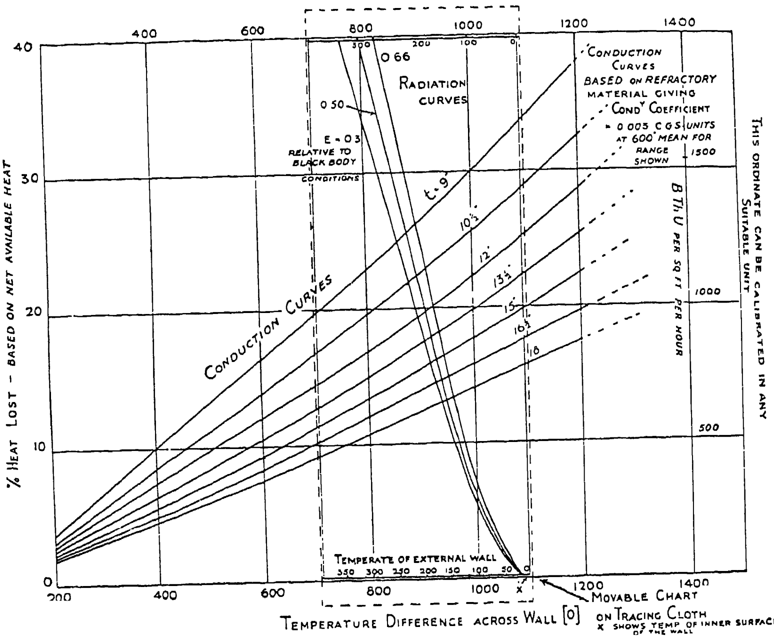


CHART FOR DETERMINING RADIATION AND CORRECTION LOSSES.

in the brochure cited above.* The radiation correction on Plate LI is applied after the manner developed by him for such conditions as the approximate data existing warrant. It is feasible to expect that at the higher temperatures radiation is considerably increased. Thus for a producer-gas obtained with a blast saturation temperature of, say, 55°, the theoretical flame temperature for combustion with 50 per cent. excess air and regenerative temperatures of 1000° is about 2400° C., whereas, according to Groume-Grjimailo † the effective flame temperature is more nearly 1850°, a figure more in keeping with practical observations. This would entail a heat content of the flame 23 per cent. below that which would obtain under non-radiating adiabatic conditions.

This is not the occasion to enter deeply into the very complex theoretical considerations bearing on these reservations, but it may not be out of place to indicate the directions in which equilibria in flame tend to operate. With regard to the water-gas equilibrium,

$$CO_2 + H_2 \rightleftarrows CO + H_2O \ldots \pm 10 \text{ Kg. C. units per gramme-molecule,}$$

which tends to limit the instantaneous development of heat, the author and Mr. Sarjant, in the paper already mentioned, extended on theoretical grounds, the constants determined by Hahn‡ to the higher limits of temperature. They also indicated at what temperatures the dissociation of H_2O and CO_2 would become appreciable were there no disturbing factors (Table XV).

TABLE XV. § EQUILIBRIUM CONSTANT OF THE WATER GAS RE-ACTION AT VERY HIGH TEMPERATURES.

Temperature. Degrees C.	Dissociation of H_2O and CO_2.		Equilibrium Constant.
	H_2O 100x.	CO_2 100y.	$K=\frac{[CO][H_2O]}{[CO_2][H_2]}=\sqrt{\frac{y^2(1-x)^2}{x^2(1-y)^2}}$
1500	0·3	0·7	5·20
2000	2·0	8·2	8·10
2500	9·5	36·5	11·70
3000	23·0	70·4	16·5

* "Coal and its Scientific Uses," (Longmans), p. 250.

† *Fours à Flammes.* Translated by L. Douglatch and A. Rothstein. Dunod et Pinat, Paris, 1914.

‡ *Zeitschrift für physikalische Chemie,* vol. xliii. p. 705, and vol. xliv. p. 513 (1903).

§ "Theoretical Chemistry," by W. Nernst (Macmillan & Co.); Bjerrum, *Zeitschrift für physikalische Chemie,* vol. lxxix. p. 537 (1912).

Le Chatelier has shown * that the dissociation of CO_2 is only perceptible in melting furnaces and in ordinary flames, and is vanishingly small in the case of explosives. Moreover, at fairly high temperatures and normal pressures the law of mass action demands that the disturbing influence of dissociation may be entirely eliminated by the presence of a small excess of oxygen.

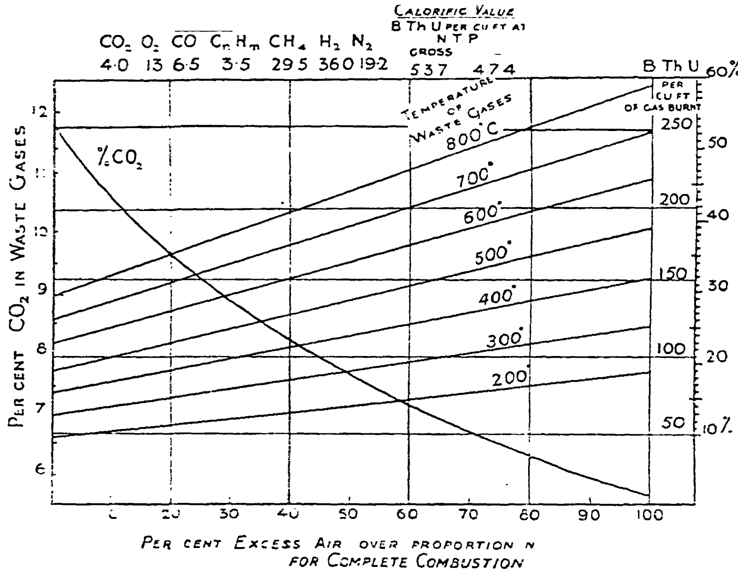
The size of the flame is undoubtedly influenced by the manner of mixing and the proportion of air used (the aeration). The process of successive oxidation in conditions far from adiabatic is a characteristic of the " lazy " flame, described by Groume-Grjimailo in the French of his translators as " douce et languissante," so much to be desired in low-temperature processes. Incidentally he points out that this flame must be obtained by a minimum use of excess air, whereas the frequent method employed is to obtain the lower temperature by undue use of air in excess and consequent distribution of the heat units to the atmosphere *via* the chimney. The more frequent cause of excess air in furnaces is inleakage, through doors, brickwork and seals. It is in such cases as this, when we come to coal-fired furnaces, that the skill of the furnaceman in the use of the damper means so much to the fuel-consumption.

Fearing for the life of the roof of his furnace, the open-hearth smelter floods the furnace with air, and in order to pump sufficient heat units into the charge has perforce to use an inordinate quantity of gas. Indeed it is a *sine qua non* with some operators that the air valve should always be left well open, whereas the better method is to operate with less air and gas, so as to ensure a short, hot flame.

In all high-temperature processes, where turbulence can be brought about it should be, as it aids the inherent heat conductivity of the flame in developing the heat units at the point where they are most needed, namely, in close proximity to the mass to be heated. Further, the rate of heat transfer is proportional to a power of the gas velocity, which varies according to whether the connection is " forced " or " natural."

Determination of Combustion Efficiency.—In the previously mentioned paper on " Fuel Control in Metallurgical Furnaces," the author and Mr. R. J. Sarjant devoted special attention to the determination of combustion efficiency and

* *Ibid.*, 1888, vol. ii. p. 782.



RELATION BETWEEN CO_2 EXCESS AIR AND HEAT LOST IN WASTE GASES.

waste heat losses. As there stated, attempts have been made, with a measure of success, to construct devices for the automatic control of the gas mixture in the case of burners for town's gas, and a number of suggestions have been made with respect to optical indication, measurements of gas flow, and what amounts virtually to analysis of the mixture.* The obstacle which has first of all to be overcome in the control of flame mixtures from observation of phenomena exhibited by the unburnt mixture is the difficulty of obtaining a true sample. Many of the burners at present on the market only complete the mixing in the furnace chamber. Failing a true sample of the unburnt mixture, the only reliable method of determining the efficiency of combustion is to combine determinations of the CO_2 (and any unburnt gas) in the waste gases, and observations of waste heat temperatures, with a knowledge of the composition of the gas used, obtained from periodical gas analysis. From a chart compiled in the manner shown in Plate LII the waste heat losses can then be readily attained, and at the same time the efficiency of the combustion checked.

Conduction and Radiation Losses.—In the method delineated for tracking down the heat units, having determined the waste heat losses and the useful heat conveyed to the material heated from its mean temperature and mass, there remains a large surplus of heat, the distribution of which it is desirable to know. From the insufficiency of data, this becomes the most difficult matter, and only approximations can be made.

In all questions of efficiency in metallurgical furnaces there is an outstanding need for much further data with regard to the thermal measurements, which must serve as an effective aid to the task of tracking down the distribution of the heat units. Particularly is this the case with regard to the specific heats and heat conductivities of refractory materials. The latter were dealt with by E. Griffiths before the Faraday Society in 1917,† and the information he gave should serve as a useful guide. Other information of value on this and other questions relative to thermal measurements is to be found in J. W. Richard's "Metallurgical Calculations." Valuable assistance can be derived from such data as do exist if applied judiciously.

Ultimate measurements must be based on actual experimental observations on the materials used. It is desirable, for instance, to base measurements of loss of heat from furnace walls on comparative laboratory tests of conduction and radiation phenomena made on representative materials, and due allowance must be made for the inevitable variations that occur in different consignments of material.

Reliable means of determination of the inside and outside temperatures of the walls are not readily at hand, and the task becomes complicated by the uneven distribution of heat and any complexity of design. The absolute value of the heat conductivity of the materials of the walls is well-nigh impossible to attain under the average works conditions. These are essentials necessary for any determination of the heat passing through the walls. The measurement of radiation losses by the application of the Stefan-Boltzmann Law is possible, given the temperature of the radiating surface. By a combination of the two methods a fairly effective method of approximations by graphical solution can be used. A series of graphs of the heat conducted through walls for different temperature gradients in terms of a standard thickness of firebrick of known conductivity are combined on the same diagram (Plate LI) from the well-known relation :—

$$Q = \frac{A\theta K}{t}$$

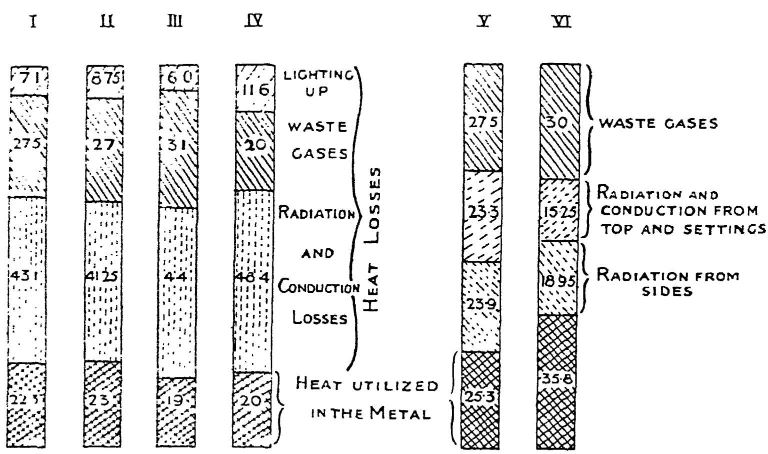
where K = coefficient of heat conductivity.
Q = quantity of heat passing in unit time across wall.
θ = temperature difference across the walls.
t = thickness of wall.
A = area of surface.

Circular and irregular-shaped surfaces can be dealt with by applying integration formulæ.

Reading to the same scale of temperature, a graph of the radiation losses from the same surface (or a number of them, according to the various emissivity constants prevailing) is prepared and drawn on a piece of tracing cloth. Since the following relation must hold, that

Heat conducted through the walls = heat lost by radiation, &c.,

the point of intersection of the two curves of heat of conduction and of radiation must indicate the actual heat loss. By setting



HEAT DISTRIBUTION CHART FOR GAS FIRED FURNACES.

the point marked x on the upper chart over, say, the approximate temperature of the inner wall and noting the point of intersection of the two curves concerned, the heat loss and the temperature of the external surface of the wall are obtained, and the right set of conditions has been chosen if the actual temperature of the external wall approximates to the value read from the chart.

The particular type of radiation formula used is that developed by Professor J. W. Hinchley in a course of lectures on Chemical Engineering at the Imperial College of Science and Technology, and is of the form :

$$L = a(T_h{}^4 - T_a{}^4) + b(T_h - T_a)^{1 \cdot 25}$$

Where L = total heat loss.
T_h = temperature (degrees abs.) of the hot surface.
T_a = temperature (degrees abs.) of the hot air.
a = Péclet or emissivity constant.
b = Constant dependent on atmospheric conditions prevailing.

At the same time it becomes possible to determine at once what saving of heat will follow the increasing of the thickness of the furnace wall by any other lagging material, and this information, combined with the cost of the extra material and the amount of "lighting up" gas needed to raise it to its temperature, will indicate what the economic dimensions should be. Further, the slope of the radiation curve for different emissivity constants will indicate the degree of any possible saving from the coating of the walls with special preparations, provided the value of this constant is known for the material from laboratory determinations.

Practical Applications.—With the heat balance of the furnace thus worked out, we are in a position to review the thermal economy of the whole furnace in relation to the special metallurgical demands of the process. What the saving is likely to be in any improved control of combustion is evident at once from the chart (Plate LII), and in our review of the whole of the facts any possible changes in the design—for example, as to whether the volume of the combustion space is correctly related to the size of material heated, and to the conditions of combustion prevailing—are indicated, and the effect of these traced by a similar method.

A heat-distribution chart for a number of gas-fired furnaces is given (Plate LIII) by way of illustrating the method. By means

of this chart it has been possible to foreshadow the only changes likely to result in fuel economy. Thus, in the case of the waste heat the possible saving was only in the region of 5 per cent. Reduction of the radiation loss would entail reconstruction of the furnaces in certain respects, or a modification of the metallurgical process. Experiments are being continued in the attempt to make practical use of this information in respect of flame control and the selection of refractory materials.

Finally it must be emphasised that the economical utilisation of fuel cannot be brought about in a hurry. It can only be the result of long and patient labour, and the cordial co-operation of all associated with its use.

Comparison of Furnaces.—Though any general comparisons must be accepted with caution owing to the great number of variables concerned, both in basic conditions and in the requirements of service, readers will probably be interested in the data given by Table XVI, concerning the cost and efficiency of coal, gas, and electric furnaces in heating and melting steel and iron.

The principal conclusions to be drawn from this table are as follows :—

(*a*) As regards conservation of fuel resources, both practically and theoretically, coal-heating comes out the best, though in gas-heating, when the coke and other by-products have been obtained from the coal, there is a considerable offset. Electrical heating in any case does not come out well in this respect, that is, it is wasteful of fuel resources.

(*b*) In cost, based on present prices, gas-heating comes out intermediate between coal-heating and electrical-heating, the latter being a very bad third compared with the other two.

(*c*) As regards electrical-heating, this is clearly expensive, whether for melting furnaces or for reheating furnaces. It must, however, be freely admitted that the greater expense is offset to some extent by the greater efficiency of the furnace—that is, this method of obtaining heat makes better use of the energy input and also gives much better control. Neither of these advantages can be expressed in pounds, shillings, or pence. In addition, electrical methods enable certain raw materials to be dealt with in a manner not possible with any other system, whether as regards fuel

Table XVI.

Comparison of Coal, Gas and Electric Furnaces for Heating and Melting Steel and Iron.

Based on one ton of Steel or Iron, heated or melted.

—	Amount of Fuel or Energy Consumed.	Thermal Units in Fuel (B.Th.U.)	Cost of Fuel. Price	Cost of Fuel. Total Cost	Heat Efficiency %	Lost Heat %	Tons of Coal Used in Producing Fuel or Energy. Tons	Tons of Coal Used in Producing Fuel or Energy. Quality
		Heating one ton of Steel to 900° C.						
	Coal Heating.							
(A) Theoretical 100 % Efficiency . .	·0182 ton (41 lb).	570,000	s. d. 24 6 ton.	s. d. — 5·4	100	*Nil.*	·018	Ordinary
(B) Practical .	·08 ton (179 lb.).	2,510,000	24 6 ton.	1 11¾	23	77	·08	,,
(A) Theoretical 100 % Efficiency . .	Gas. 1,140 cubic feet.	570,000	s. d. 1 8 1,000 c. feet.	1 10·8	100	*Nil.*	·076	Bituminous.
(B) Practical .	3,580 cub. feet.	1,790,000	1 8 1,000 c. feet.	5 11·6	32	68	·24	,,
(A) Theoretical 100 % Efficiency . .	Electrical. 166 units	570,000	·66d. unit.	9 1½	100	*Nil*	·21	Boiler coal
(B) Practical .	300 units	1,030,000	·66d.	16 6	54	46	·38	,, ,,
		Melting one ton of Iron in the Cupola.						
Practical .	Hearth. ·15 ton coke (336 lb.).	4,370,000	s. d. 48 0 ton.	s. d. 7 2	23	77	·225	Coking Coa
		Melting and finishing one ton Fluid Steel.						
Practical .	Crucible. 2·50 ton crucible coke.	73,000,000	s. d. 33 6 ton.	s. d. 83 9	1·4	98·6	3·75	Coking coal
Practical .	Open Hearth. ·30 ton producer coal.	9,400,000	22 0	6 6¾	13·5	86·5	·3	Producer coal.
Practical .	Electric, to melt. 515 units	1,780,000	·66d. unit.	28 4	68	32	·66	Boiler Coal
Practical .	Electric, to melt, & refine 780 units	2,680,000	·66d. unit	42 11	47	53	1·0	,, ,,

In compiling the above table, the calorific power taken for the various fuels is as follows—

1 electrical unit	= 3,440	B.Th.U.
1 cubic foot coal gas (town's)	= 500	,,
1 lb. coal	=14,000	,,
1 lb. crucible coke	=13,000	,,
1 lb. cupola coke	=13,000	,,

The average Specific Heat of Steel between 0° C. and 900° C. equals ·16.

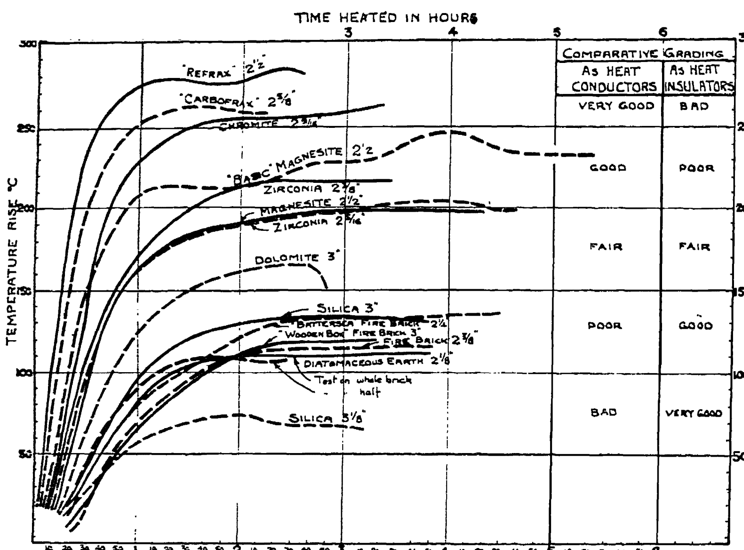
directly burnt or by first turning fuel into gas. In the works of the author's firm it has been a liberal education to see material being used up which in ordinary times would have been condemned to the scrap-heap. The use of small turnings is referred to in this connection, and whilst they can be employed by briquetting, this is somewhat costly, takes up time and demands plant and men to run it. We are, therefore, greatly indebted to the electrical engineer and to those who have so ably developed the electric furnace. The author well remembers how at first there was a tendency to scoff at the employment of electrical energy for this purpose. There is, therefore, great credit due to the prescience of Sir William Siemens, who was probably the first to make a proper electric furnace, small as it was, capable of melting material having such high melting points as iron and steel. It is now nearly half a century since Sir William Siemens constructed and patented his electric arc furnace for melting steel. Much later, in fact within the past twenty years or so, great credit has been due to the French metallurgist, Monsieur Héroult, whose first patent was obtained in 1887, and from whose work great benefit has accrued to the world.

Refractory Materials for Furnaces.—The need for increased knowledge of the properties of refractory bricks as used in furnaces has already been emphasised and, in this connection, it is interesting to refer to Plate LIV, which presents the results of experiments made in the Hadfield Research Laboratories concerning refractory bricks of different types. The bricks tested were as follows: (1) Refrax; (2) Carbofrax; (3) Chromite; (4) "Basic" Magnesite; (5) Zirconia; (6) Magnesite; (7) Dolomite; (8) Silica; (9) "Wooden Box" Firebrick; (10) Diatomaceous Earth.

The information presented by this chart is of considerable assistance wherever high-temperature furnaces are concerned.

Besides increased knowledge concerning the properties of existing refractories, there is a need for improved refractory materials both metallic and non-metallic, and this need extends to all classes of furnaces.

For example, the utilisation of high calorific intensities in boiler operation depends upon improvements in the material of which the furnace chamber is constructed, i.e., both refractories and metallic materials. It calls for the provision of a



RELATIVE HEAT INSULATING VALUES OF REFRACTORY BRICKS.

double wall to the furnace chamber, refractoriness being the primary consideration for the inner lining, heat insulation that of the outer ; it has not yet been found possible to obtain in one and the same material the maximum development of these two properties. Also, there is a limit to the practical intensities of evaporation by reason of the failure of the tubes in the case of water tube boilers.

The application of the air heater to boiler plants is a growing development, though at present it appears that the range of actual improvement in efficiency is in the region of 5%. But further application of this type of accessory to increase the output of steam will be more readily possible when the use of special non-scaling materials becomes general practice on mechanical stokers. The fusion ranges of the low grade fuels often burnt on such appliances have to be considered, but the running of a fusible slag through the bars is no disadvantage if such bars are not attacked by the fused ash. Indeed the lines of progress mentioned call for special improved materials in all directions, and with high rates of evaporation should become an economical proposition.

In this connection, reference may again be made to the "Era" non-scaling steel which has already been mentioned in Chapter X. The high strength preserved by this steel at high temperatures, as well as its non-scaling properties, render it particularly valuable in furnace construction. By its use, maintenance costs are reduced and it becomes possible to operate furnaces at higher efficiencies.

Instruments and the Human Element.—In pointing out the importance of measuring instruments as an aid to the determination of furnace conditions and as a means of increasing combustion efficiency, the author wishes to avoid separating those methods of measurement which require the use of instruments of precision, from the systematic methods undertaken by that most wonderful of all instruments, the human faculty. In the practical affairs of a works where the operative factors are many and varied, instruments should be considered rather as an aid to and not as a substitute for the human element.

The individual, for example, using the pyrometer, the pressure gauge or the CO_2 recorder must temper his faith in the infallibility of his tools with his own observational capacity. Accordingly, in pursuing the aim for measurement rather than guesswork we all look forward to the day when it will be

possible to have furnace practice on as precise a basis as that now possible in the boiler room.

Pyrometry.—In view of the importance in metallurgical operations of determining high temperatures, that is, from 500° to 2000° C., it is of considerable interest to remember that this great work was originated by Josiah Wedgwood, who was born in Burslem, in 1730. The accompanying portrait (Plate LV) of "the great Wedgwood," as Gladstone termed the Staffordshire potter sixty years ago when opening the Burslem Institute in commemoration of him, is taken from a miniature in Wedgwood ware itself, prepared by Mr. Harry Barnard, of Stoke.

Wedgwood's first paper was read before the Royal Society, being presented in 1782 through the President of that day, Sir Joseph Banks, Bt. This description of his researches led to him receiving the honour of being selected as a Fellow of the Royal Society, and deservedly so, for undoubtedly this was the first attempt on record to determine accurately high temperatures.

The title of his paper, "An attempt to make a thermometer for measuring the higher degrees of heat, from a red heat up to the strongest that vessels made of clay can support," describes the problem which Wedgwood set himself. How clearly he appreciated its importance, and how scientific were the methods which he adopted, may be gathered from the following extract from the paper cited:

> "A measure for the higher degrees of heat such as the common thermometers afford for the lower ones, would be an important acquisition, both to the philosopher and the practical artist. The latter must feel the want of such a measure on many occasions.
>
> "In a long course of experiments for the improvement of the manufacture I am engaged in, some of my greatest difficulties and perplexities have arisen from not being able to ascertain the heat to which the experiment-pieces had been exposed. A red, bright red, and white heat, are indeterminate expressions, and even though the three stages were sufficiently distinct from each other, they are of too great latitude, as the brightness or luminousness of fire increases with its force, through numerous gradations which can neither be expressed in words nor discriminated by the eye.
>
> "The force of fire, in its higher as well as lower stages, can no otherwise be justly ascertained than by its effects upon some known body."

Wedgwood then goes on to explain the principle and use of two types of thermometers, one based upon the distinctive colours produced in "compositions of calces of iron with clay"

JOSIAH WEDGWOOD, F.R.S.
(1730–1795).

by different degrees of heat, and the other depending upon the progressive contraction of clay at increasing temperatures.

The range of colours obtainable in the discs of " calces of iron with clay " extended from flesh colour, through chocolate to nearly black, and by placing such discs in a glass tube mounted alongside an arbitrary scale, Wedgwood obtained quite a serviceable standard. It was only necessary to match, against the set of reference discs, the colour of a disc heated with any particular batch of pottery in order to obtain an indication of the degree of heat to which the latter had been exposed.

Wedgwood found, however, that the diminution in bulk of argillaceous bodies by fire gave " a more accurate and extensive measure of heat than the different shades of colour." The total contraction which he observed in some good clays, heated in the strongest of his fires, amounted to considerably more than one-fourth part in every dimension. By paying due attention to the composition and quality of the " thermometer pieces," and devising means for measuring their contraction " with ease and minute accuracy," Wedgwood obtained what he considered to be " a measure of fire sufficient for every purpose of experiment or business." It was, of course, necessary to correlate the degrees of temperature as determined by this means with the known heats of various processes, and it is interesting to learn from his account what " fixed points " Wedgwood selected in order to interpret the arbitrary scale of his thermometer pieces. The figures which he gives concerning metallurgical operations are specially interesting, and they show clearly how great was the need in those days for even an approximate method of measuring high temperatures. The relevant passages from the paper are as follows :—

> " It now only remains, that the language of this new thermometer be understood, and that it may be known what the heats meant by its degrees really are. For this purpose a great number of experiments has been made, from which the following results are selected.
>
> " The scale commences at a red-heat, fully visible in daylight ; and the greatest heat that I have hitherto obtained in my experiments is 160°. This degree I have produced in an air-furnace about eight inches square.
>
> " Mr. Alchorne has been so obliging as to try the necessary experiments with the pure metals at the Tower, to ascertain at what degrees of this thermometer they go into fusion, and it appears that Swedish copper melts at 27, silver at 28, and gold at 32.
>
> " Brass is in fusion at 21. Nevertheless in the brass and copper foundries, the workmen carry their fires to 140° and upwards ;

r what purpose they so far exceed the melting heat, or whether great an additional heat be really necessary, I have not learnt.

"The welding heat of iron is from 90 to 95; and the greatest ɜat that could be produced in the common smith's forge, 125.

"Cast iron was found to melt at 130°, both in a crucible in my wn furnace, and at the foundry; but could not be brought into ısion in the smith's forge, though that heat is only 5° lower. The ɜat by which iron is run down among the fuel is only 5° lower.

"As the welding state of iron is a softening or beginning fusion f the furnace, it has been generally thought that cast iron would ıelt with much less heat than what is necessary for producing this ffect upon the forged; whereas on the contrary, cast iron appears ɔ require for its fusion, a heat exceeding the welding heat 35 or 0°, which is much more than the heat of melted copper exceeds ıe lowest visible redness.

"Thus we find that though the heat for melting copper is by ome called a white heat, it is only 27° of this thermometer. The velding heat of iron, or 90°, is likewise a white heat; even 130° at vhich cast iron is in fusion, is not more than a white heat; and so n to 160° and upwards is all a white heat still. This shews ıbundantly how vague such a denomination must be, and how nadequate to the purpose of giving us any clear ideas of the extent of what we have been accustomed to consider as one of the three livisions of heat in ignited bodies.

"A Hessian crucible in the iron foundry, viz. about 150°, melted nto a slag-like substance. Soft iron nails, in a Hessian crucible n my own furnace, melted into one mass with the bottom of the ɜrucible, at 154°; the part of the crucible above the iron was little injured.

"The fonding heat of the glass furnaces I examined, or that by which the perfect vitrification of the materials is produced, was at one of them 114° for flint glass, and 124° for plate-glass; at another it was only 70° for the former, which shows the inequality of heat, perhaps unknown to the workmen themselves, made use of for the same purpose. After complete vitrification, the heat is abated for some hours to 28 or 29°, which is called the settling heat; and this heat is sufficient for keeping the glass in fusion. The fire is afterwards increased for working the glass, to what is called the working heat; and this I found in plate glass, to be 57°.

"Delft ware is fired by a heat of 40 or 41°; cream-coloured or Queen's ware, by 86°; and stone ware, called by the French *pots de grès*, by 102°; by this strong heat it is changed to a true porcelain texture, about 110°.

"A piece of an Etruscan vase melted at 33°; pieces of some other vases and Roman ware about 36°; Worcester china vitrified at 94°. Mr. Sprimont's Chelsea china at 105°; the Derby at 112°; and Bow at 121°; but Bristol china showed no appearance of vitrification at 135°. The common sort of Chinese porcelain does not perfectly vitrify by any fire I could produce, but began to soften about 120°, and at 156 became so soft as to sink down, and apply itself close upon a very irregular surface underneath. The true stone Nankeen, by this strong heat, does not soften in the least, nor does it even acquire a porcelain texture, the unglazed parts continuing in such a state as to imbibe water and stick to the tongue. The Dresden porcelain is more refractory than the common Chinese, but equally so with the stone Nankeen. The

cream-coloured or Queen's ware bears the same heat as the Dresden, and the body is as little affected by this intense degree of fire.

"Mr. Pott says, that to melt a mixture of chalk and clay in certain proportions, which proportions appear from his tables to be equal parts, is 'among the master-pieces of art.' This mixture melts into a perfect glass at 123° of this thermometer.

"The whole of Mr. Pott's or any other experiments may, by repeating and accompanying them with these thermometric pieces, have their respective degrees of heat ascertained, and thereby be rendered more intelligible and useful to the reader, the experimenter, and the working artist."

Though it is a far cry from Wedgwood's efforts to the latest results obtained by means of electrical and optical pyrometers, devised by le Chatelier, Callendar, Roberts-Austen, and others, yet the preceding account of Wedgwood's early work is of enduring interest. It is now as easy to know accurately what are the conditions in a high-temperature furnace, or in any metallurgical operation, as it was formerly difficult or impossible. It is nearly 150 years since Wedgwood made the first steps in this field, and for many years thereafter progress was slow and difficult. Indeed it is only during the last 27 years or so that rapid advance has been made, culminating in the easy and accurate methods at our disposal to-day.

Up to the end of the last century the means of correctly determining temperatures were indeed few and far between. The thermocouple pyrometer based on electrical resistance, the resistance pyrometer, and the optical pyrometer, were but little known or applied except in the laboratory. As regards accurate determinations of high temperatures, the author would like to refer to the great help rendered to the world generally by his friend, Professor H. le Chatelier, who has been the eminent leader of scientific research and advance in this respect, both in relation to the electrical and the optical pyrometer. Professor Callendar's valuable scientific work in this line of research should also be mentioned.

It was only as recently as 1891 that the author first entered into correspondence with Professor le Chatelier, with regard to the pyrometer the latter had then devised, and at that time le Chatelier himself thought that a scientific instrument could not be used by the practical man, for he stated :—" Je ne crois pas que mon pyromètre électrique puisse jamais être, soit d'une façon courrante, entre les mains des ouvriers." As showing the immense progress realised since those days it may be mentioned that, during the war, there were made weekly at the

works of the author's firm alone some 50,000 separate determinations of high temperatures by electrical and optical pyrometers. This necessitated the employment of about sixty assistants, who devoted practically the whole of their time to this work. Each determination required control or checking and keeping in order by those who had a certain amount of scientific training.

In 1922 Professor H. le Chatelier delivered a most interesting address on the occasion of his "Cinquantenaire Scientifique," when a presentation was made to him of 170,000 francs. Upon his request 100,000 francs of this total were handed over to the Academy of Sciences to create a Scholarship of Industrial Science. In one part of his address Professor le Chatelier was kind enough to say that the author had inspired him to take up his researches on optical pyrometry. It was very little that the author was able to do, but he did see the outstanding importance, in fact, the absolute necessity, of improving our methods at that time, specially as regards obtaining correctly and quickly measurements of high temperatures in a practical way.

At the present time there are available efficient pyrometric appliances of various forms and types, adapted, except in some specially difficult circumstances, to practically every requirement. It is neither necessary nor possible here to go into the question of their nature and mode of application. Those interested will find an excellent literature on the subject, and if contemplating the use of pyrometers, or improving their existing installations, they cannot do better than place themselves under the advice of one of the firms who make a speciality of these appliances.

In practice, certain difficulties are encountered in the measurement of temperature, specially in the means of applying pyrometers, and it is not always possible to circumvent them. By the use of optical and radiation pyrometers, we are able to cover the whole range of temperature involved in manufacturing processes, and the pyrometers are accurate in themselves, but they cannot always be applied so as to give a true indication of the temperature of the object. In the case of steel manufacture there is flame which either in the case of the optical pyrometer affects the readings by its luminous effects, or in the case of the thermo-electric pyrometer, may cause the thermocouple to be heated above the temperature of the object. The

temperature in the interior of a large mass, if inaccessible to a thermocouple, is more or less a matter of conjecture.

It cannot be too much emphasised that the thermo-electric pyrometer actually measures not the temperature of the heated object under investigation, but the temperature of its own couple. If the temperature under investigation is to be measured accurately the thermocouple must be at that temperature.

Finally, it should be emphasised that the accurate operation of pyrometers requires considerable intelligence, and, in fact, a knowledge of the scientific principles underlying their use. In the author's firm, where the heat-treatment processes have now been under pyrometric control to their great advantage for the past 25 years, it has been found necessary to devote a special laboratory to the care and maintenance of pyrometers, under the charge of scientific assistants.

Fuel Economy in Iron and Steel Manufacture.—An important report* presented at the Autumn Meeting, 1919, of the Iron and Steel Institute, on behalf of the British Association Fuel Economy Committee, dealt with investigations, the prime object of which was to obtain reliable data as to the present state of fuel consumptions and economy in regard to (*a*) blast-furnace practice, and (*b*) steelworks and rolling-mills producing ordinary steel sections. These branches of manufacture account for an overwhelming proportion of the total coal used in the production of iron and steel, as distinguished from the subsequent fabrication of these materials into various implements and machines in engineering establishments. The Committee therefore decided not to complicate the subject by extending very far their inquiries into the manufacture of crucible and special alloy steels. In the latter, "heat treatment" plays such an essential and prominent part that fuel economy *per se*, although important, must always be regarded as subordinate to the ultimate quality of the product. Dr. Stead, however, obtained some information from two Sheffield firms as to their coke consumptions in the melting of crucible steel; this information was included in the Report, because it raised the question of the alleged unsuitability of "by-product" coke for that purpose.

* "Report on Fuel Economy and Consumptions in the Manufactur of Iron and ——" by Professor W. A. Bone, D.Sc., F.R.S. (Chairman), Sir Robert Hadfield, Bart., F.R.S., and Mr. Alfred Hutchinson B.A., B.Sc.

Also in regard to cupola practice in iron foundries, the fact that conditions differ so greatly, according to the type of castings produced, makes the drawing of comparisons or the deduction of general conclusions so difficult that it was deemed inadvisable to include this aspect of the subject in the scope of the inquiry. Moreover, as Mr. H. James Yates of Birmingham (Vice-Chairman of the Committee) had prepared a valuable memorandum embodying his experience in cupola practice, it was thought better that he should present it, on behalf of the Committee, as a separate contribution* to this discussion, which he kindly consented to do.

Early Work of British Metallurgists in Fuel Economy.—It may be justly claimed that, for at least three-quarters of a century after James Neilson's epoch-making invention of the use of hot-blast in 1828, British metallurgists led the way in regard to fuel economy in the manufacture of iron and steel. The mere recital of such names as those of Lowthian Bell, Charles Cochrane, Thomas Whitwell, E. A. Cowper, and Henry Bessemer, all of whom may be said to have accomplished their principal work within the period 1850 to 1885, is sufficient evidence of the supremacy of British technology in this particular direction during the latter half of the nineteenth century.

Limits of Fuel Economy in the Blast-Furnace defined, 1872.—Bell, who had been investigating the matter in his laboratory from a fundamental standpoint, was perhaps the first metallurgist to realise the operation of the "law of mass action" in the smelting of iron. This important principle had been enunciated by Berthollet in his celebrated "Essai de Statique Chemique" in 1803, but it had never been generally accepted by chemists until Guldberg and Waage revived it in 1867. Bell at once grasped its importance, and discovered in his laboratory the reversibility of the interactions between carbonic oxide and the oxides of iron at all temperatures in the blast-furnace:

$$\mathrm{Fe}_x\mathrm{O}_y + y\mathrm{CO} \rightleftharpoons y\mathrm{CO}_2 + x\mathrm{Fe}.$$

It was this discovery, and Bell's convincing exposition of it in his "Chemical Phenomena of Iron Smelting," which proved beyond all question that the natural laws governing the reduction

* "Fuel Economy in Cupola Practice," by H. James Yates.

of the ore in the blast-furnace make it impossible to utilise, within the furnace itself, more than a certain fraction (which Bell seems to have considered as about 53 per cent.) of the total available energy of the coke charged into it. Upon this cardinal fact, which confronts every ironmaster, the whole question of fuel economy in iron and steel works may be said to hinge.

Having satisfied himself of the truth and far-reaching importance of his discovery, Bell proceeded logically to define the practical limits of fuel economy in a Cleveland blast-furnace. He clearly saw that there would be certain limiting conditions, both as regards furnace dimensions (particularly height) and blast temperatures, beyond which no further economy in fuel would result; and the Ferryhill experience showed him that, as regards dimensions, these limits had probably been reached. He also considered that it would not be practicable to preheat the blast beyond 1000° C., and that already, even in 1872, Cleveland ironmasters were nearing the practicable limit of fuel economy in their furnaces.

His main conclusions on the matter may be summed up in the following statements, namely:

(1) that no advantage can possibly accrue from an increase in the height or capacity of the furnace beyond the limits which would permit of the gases leaving the furnace at a temperature of about 300° C., and

(2) that the practical limit beyond which the reducing power of the gases cannot be further utilised in the furnace is reached when at their point of exit therefrom, and at a temperature of 300° C. they contain 45 to 50 of carbon dioxide to every 100 of carbon monoxide by volume.

Bell's Estimate for Limits of Fuel Economy in Smelting Cleveland Ironstone.—He held that, in regard to Cleveland practice, the limiting furnace dimensions would be a height of 80 feet combined with a capacity of 16,000 cubic feet, and he expressed the opinion that "taking the ordinary run of Durham coal and Cleveland ironstone, the ironmaster who produces a ton of No. 3 iron with 21½ cwt. (of coke), with the blast heated to 500° C., may consider himself working very closely up to the limits of economy which are prescribed by the nature of the materials he is operating upon," and that "it is useless to hope to smelt a ton of grey iron from the Cleveland stone yielding 41 per cent. of pig metal with anything notably under 20½ cwt. of coke."

Reviewing contemporary practice, Bell estimated that, by having increased their furnace dimensions and blast temperatures, Cleveland ironmasters had already, by the year 1872, effected a saving equivalent to 1 million tons of coal per annum, exclusive of a further 0·75 million tons which had accrued from their having adopted the practice of using the waste gases from the furnace for preheating the blast, and for raising steam in their boilers to drive the blowing-engines. But, as he had stated, they had even then almost reached the practical limit of fuel economy so far as the actual coke consumption in the furnace itself was concerned.

These notes from the history of fuel economy in the blast-furnace during the fifty years (1830–79) following James Neilson's inventions, are important, because they show that in those days British ironmasters led the way in the matter.

Henry Bessemer, 1856.—As regards the conversion of the crude product of the blast-furnace into steel, it was Henry Bessemer who, in a paper read before the British Association in 1856, announced to the world his wonderful discovery that this can be effected on a commercial scale simply by blowing air through the molten metal without the expenditure of any additional fuel beyond that required to generate the blast. Indeed, perhaps the most striking feature about Bessemer's process was that the temperature of the bath could be maintained at a sufficiently high degree merely by the oxidation of the metalloid impurities present.

Snelus, 1872 ; Thomas and Gilchrist, 1880.—The extension of this "pneumatic" process to dephosphorising iron in a basic-lined converter, which was first proposed by Snelus in 1872, and finally brought to a practical success a few years later by Thomas and Gilchrist, completed a series of inventions which, from the point of fuel saving in the manufacture of steel, have perhaps not been excelled.

The Brothers Siemens.—Contemporaneously with these great advances, the brothers Siemens were successfully applying their open-hearth "regenerative" furnace to the manufacture of steel. They first gasified the fuel by partially burning it in a separate furnace, termed the producer, and then preheated both the resulting gas and the air necessary for its combustion to above 1000° C., by passing each separately through firebrick chequered chambers ("regenerators") which had previously been raised to a high temperature at the expense of the sensible heat

in the waste gases from the furnace. The gas and air, thus preheated, were conducted by separate flues to the hearth of the furnace where combustion took place with the production of a high enough temperature to maintain the decarburised iron in the necessary fluid condition for its further refinement.

Thus it may be said that, from the labours of all these distinguished investigators during the period 1856 to 1880, inclusive, there emerged the cardinal principles of fuel economy in the manufacture of steel which we to-day chiefly rely upon. Most of the subsequent developments that have been made in this connection have been mainly in details, such as larger furnace dimensions, improvements in mechanical accessories, and a better understanding of the underlying principles of gas-producer practice made possible by recent developments in the science of gas reactions.

Organisation of Fuel Economy in Modern Iron and Steel Works.—As stated in the Report of the British Association Fuel Economy Committee, to which reference has already been made, and from which these notes are derived, the achievement of the utmost fuel economy in a modern iron and steel works is essentially a matter of the scientific organisation and disposition of the plant as a whole, with a view to utilising to the best advantage, in the steelworks and rolling-mills, the energy in the surplus blast-furnace and coke-oven gases. For this has been shown to be sufficient, not only for converting molten iron from the blast-furnace into steel, but also for rolling the resulting ingots into finished steel sections.

The possibility of attaining such an ideal is primarily due to three great technical developments which have been made since 1880, namely:

(1) in the manufacture of metallurgical coke in chamber ovens with heat recuperation and by-product recovery, which have mainly been due to the efforts of continental (Belgian and German) chemists and engineers;

(2) in the generation of power in internal combustion engines from cleaned blast-furnace gas, the practical possibility of which was first demonstrated by the late Mr. B. H. Thwaite in 1894–5, and afterwards realised on a large scale by Messrs. Bailly and Krafft, under the leadership of the late Mr. Adolphe Greiner at the Seraing works of the Société Cockerill in Belgium; and

(3) in methods of cleaning blast-furnace gas (*a*) by water-

washing, as in the Theisen apparatus, or, preferably, (*b*) by electrostatic methods.

The economy in fuel which would result from the concentration of by-product coke-ovens, blast-furnaces, rolling-mills, and steelworks on one site, coupled with the utilisation of the combined surpluses of coke-oven and cleaned blast-furnace gases, partly in large internal combustion engines driving dynamos generating electricity for operating the rolling-mills and all other machinery on the plant, and partly also to displace producer-gas in the steel furnaces and soaking-pits, had become manifest during the early years of the present century, largely as the result of continental experience (*i.e.* in Belgium, Germany, and Austria).

It should here be remarked that the British iron and steel industry has, in this respect, laboured under a disadvantage as compared with its continental rivals. For whereas most of our smelting plants and ironworks were established before 1880. the modern German industry arose after that period, when it was manifestly the right policy to organise and lay out iron and steel plants with the express purpose of securing all the advantages latent in such a concentration of units as has been indicated. And here, it must be admitted, the German genius for organisation, and for the logical working out of a policy based on ascertained scientific principles, had ample opportunity, which it did not fail to turn to the best advantage. Accordingly it was not surprising to find, during the decade preceding the war, that whilst the newer German iron and steel works embodied, in a marked degree, the advantages of concentration and co-ordination of units, under scientific control, the older British plants had to be gradually remodelled, as circumstances permitted, so as to conform, as nearly as possible, to the new conditions. It is therefore not necessarily disparaging to British enterprise to have to admit that, since the opening of the present century, the continental industry has probably secured a lead in regard to fuel economy, because of its comparative newness and superior organisation. At the same time, some of our British undertakings had also shown commendable enterprise in this direction.

The Practical Ideal of Fuel Economy in Steel Manufacture.—For reasons stated fully in the British Association Report, it is justifiable to regard the consumption of no more than 1·75 tons of good coking coal per ton of finished steel

sections produced as a "practical ideal" for a modern British plant comprising coke-ovens, blast-furnaces, steelworks, and rolling-mills, properly disposed on one site, and under one control and management.

Certain conditions are, however, either essential or desirable for the achievement of such an ideal. Some of the more important of these may be indicated as follows :

(1) By-product coke-ovens, blast-furnaces, steelworks, and rolling-mills must all be concentrated on one site, and suitably laid out in relation to each other.

(2) The by-product coke-ovens must be of the regenerative type, so as to yield the largest possible amount of surplus gas.*

(3) The blast-furnaces should be fitted with double bells in order to minimise loss of gas. The blast should be generated by means of a gas-driven blowing engine. There should also be a proper distribution of the materials in the furnace by means of a suitably dimensioned bell.

(4) The gases leaving the furnace should be dry-cleaned, preferably by some electrostatic method, so as to reduce their dust content to about 0·1 gramme per cubic metre. The hot-blast stoves should be heated by this dry-cleaned gas. The gas intended for generating power in gas-engines must be further cleaned until its dust content does not exceed 0·015 gramme per cubic metre.

(5) There should be separate supplies of surplus coke-oven and blast-furnace gases throughout the plant ; the mixing of the two should be carried out at the various points of consumption as required.

(6) The gas-engines in the power-house should preferably be run on cleaned blast-furnace gas only. For steel furnaces and soaking-pits a mixture of blast-furnace and coke-oven gases, in such proportion as will yield a heating gas of between 160 and 180 B.Th.U. per cubic foot, should be used.

(7) The rolling-mills should preferably be electrically (not steam) driven.

(8) There must be scientific management and control throughout the whole heating system by properly trained fuel technologists, for it is essential that every available heat unit in the

* The question of whether or no the ovens should be heated by "dry-cleaned" blast-furnace gas, in order to increase the surplus of the richer coke-oven gas, is an important subsidiary one which is worthy of attention.

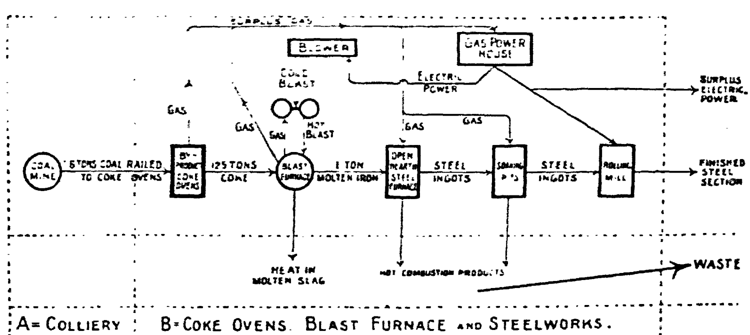
plant shall be tracked down and effectively utilised to the best advantage.

As the result of his association with Mr. T. C. Hutchinson's enterprise at Skinningrove, Professor Bone was enabled to publish, in 1916, a diagram* relative to the concentration and disposition of plant requisite for the production of a ton of finished steel sections from Cleveland ironstone and Durham coke, with the expenditure of no more than 1·6 tons of coal charged into the coke-ovens. As this diagram illustrates some of the essential features of such a scheme, it is reproduced in Plate LVI herewith.

Possible Improvements in Iron and Steel Manufacture.—The main conclusions based upon a critical investigation and comparison of data and information received by the British Association Fuel Economy Committee from some twenty-five firms engaged in the operation of blast furnaces, open-hearth furnaces (molten pig, mixed processes, and cold processes), Bessemer practice, and the melting of crucible steel may be summarized as below. Though certain advances have been made since the preparation of this Report, the encouragement of such advances being the primary reason for the investigation, the complete Report and the discussion thereon may still be read with profit for they embody data almost, if not quite, unique in completeness and value. From these, the general conclusions drawn were substantially as follows :

(1) The results, as a whole, prove beyond all question that much yet remains to be done before British iron and steel works will have attained to anything like the practical ideal of fuel economy which at least three leading iron and steel makers have declared to be even now attainable. None of the returns shows that, even where coke-ovens, blast-furnaces, steelworks, and rolling-mills are concentrated on one site and under one management, the manufacture of the steel and its subsequent rolling into finished sections have as yet been accomplished with no other expenditure of coal than that which must be charged into the coke-ovens to make the coke required for the blast-furnace. In his Memorandum to the Coal Conservation Committee in October, 1917, Mr. Benjamin Talbot estimated that a ton of finished steel sections could then be produced with no greater expenditure of fuel than 35 cwt. of coal at the coke-ovens.

* Royal Institution Lectures on "Fuel Economy and the Utilisation of Coal" 1916.



PROFESSOR BONE'S DIAGRAM ILLUSTRATING CONCENTRATION AND DISPOSITION OF PLANT AND FUEL CONSUMPTION, FOR PRODUCING 1 TON OF FINISHED STEEL SECTIONS FROM CLEVELAND IRONSTONE AND DURHAM COKE.

According to our analysis of the returns of the four firms using "the molten pig process," not one of them is using less than 40 cwt. of coal per ton of finished steel sections, and two were using about 50 to 55 cwt.

(2) There are so many directions in which further large economies may be effected, even when the necessary concentration and co-ordination of plant units have been secured, that we cannot hope to do more than indicate a few of the more obvious of them. The surplus blast-furnace and coke-oven gases can undoubtedly be much better and more fully utilised than they are to-day on most plants. The data published in this report concerning the temperatures and compositions of waste gases from boilers, stoves, furnaces, and soaking-pits, show that the science of combustion is, as a rule, either imperfectly understood or very badly applied by those in charge of the plants. A great deal of heat can, and ought to be, recovered from such waste gases.

(3) Speaking of this aspect of the subject, Mr. Talbot, in the memorandum referred to, stated: "A point in fuel economy in connection with steelworks to which a considerable amount of attention is now being directed is the utilisation of waste heat in open-hearth furnace flues by means of waste heat boilers . . . it is stated that a saving equivalent to 150 to 200 lb. of coal per ton of steel ingots has been obtained from this waste heat."

(4) Again, in a paper read by Mr. C. J. Bacon before the American Iron and Steel Institute, in 1915, it was stated that: "Existing boilers on large open-hearth furnaces are showing a saving which, when expressed in terms of fuel required in coal-fired boilers, is equivalent to at least 250 lb. of coal (11,000 B.Th.U. per lb.) per ton of ingots." Again, in a paper read in July, 1919, by Mr. C. J. Goodwin before the Annual Congress of the Society of Chemical Industry in London, it was estimated that in regenerative open-hearth furnaces, where the products of combustion, containing 5·0 per cent. of oxygen, pass up the chimney at an average temperature of 500° C., as much as 33 per cent. of the net calorific value of the fuel is thus being lost.

(5) Such satisfactory progress is now being made with the electrostatic cleaning of blast-furnace gases, that the day may be confidently anticipated when all the gas (whether required for stoves or engines) will be so cleaned. This will undoubtedly increase the thermal efficiency of the hot-blast stoves, and make a larger surplus of gas available for the steelworks.

(6) Speaking of the utilisation of the surplus gas for power purposes, it seems a barbarous practice to burn uncleaned blast-furnace gas in Lancashire boilers, the efficiency of which probably does not exceed 55 per cent., when (if cleaned) its potential energy can be transferred into electric power *via* the gas-engine and dynamo. The day is fast approaching when, in steelworks adjacent to blast furnaces, all stationary machines (including blowing-engines, cranes, and rolling-mills) will be electrically driven by current generated from the explosion of blast-furnace gas in internal combustion engines. Even now, steam-driven reciprocating blowing-engines should be superseded by electrically driven turbo-blowers.

(7) When such reforms have been carried out in connection with the blast-furnace plants, we may look for the abolition of the "gas-producer" in the adjacent steelworks, a step much to be desired. The blast-furnace is the place where all the coal on an iron or steel plant should be gasified after it has been carbonised in the coke-ovens.

(8) The problem of recovering and utilising the heat carried away in the molten slag from the blast-furnace is one which ought to be solved in the near future.

(9) We would again emphasise the view that the problem of fuel economy, as it presents itself to-day, is one rather of scientific organisation and co-ordination than of the discovery of new principles. In all the larger works there ought to be an organised staff wholly engaged, under competent direction, in controlling the fuel consumption. Such control ought not to be relegated to a member of the technical staff whose chief attention must be given to the supervision of machines or of operations in which the consumption of fuel is merely an incidental, and perhaps even subordinate, consideration. It should be borne in mind that our scientific knowledge regarding fuels and their combustion has developed so rapidly during the past twenty years that it has now become a separate branch of technology for which special training is required. Without such training the ordinary works chemist (and still more so the engineer) is not competent to handle the subject. The task of training a sufficient number of competent men is one that will tax to the utmost the resources of the various Laboratories established within recent years for the special study of fuel technology at our Universities, and the Government should be urged, as a matter of pressing and vital importance, to assist, by adequate

financial support, the extension of such educational facilities. A great deal might also be accomplished by some co-operative or collective effort on the part of a group of works in one and the same neighbourhood. Such group of firms might well unite in establishing, for their joint benefit, a common fuel laboratory and staff. The increasing cost of coal, and the present serious fuel situation, will probably compel action along some such lines.

(10) The full accomplishment of all (or indeed any of) these reforms will demand much co-operative investigation and action throughout the whole industry. But the fuel situation has now become so serious in this country, that the industry ought to cast aside sectional or individual interests or jealousies in a mighty and patriotic concerted effort to achieve the utmost efficiency and economy in its use of coal. It is a duty that it owes both to the present generation and to posterity. The British Association Fuel Economy Committee, on whose behalf and in whose name we speak, will feel that its work has not been in vain if, as the result of their reading and discussing this Report, the leaders of the iron and steel industry inaugurate a movement that will not end until the "practical ideals" set before them in it have been achieved.

Steel Melting Furnaces.—According to Professor J. W. Richards, of the Lehigh University, U.S.A., as stated in his excellent work "Metallurgical Calculations," taking the average heat-content of melted steel to be 300 calories per kilogramme (different determinations range from 275 to 350 calories per kilogramme), we have:

Theoretical amount of heat = 300 × 1016.
= 304,800 calories per ton of steel melted.
= 1,200,000 B.Th.U. per ton of steel melted.

This figure cannot, of course, be approached in practice because it does not allow for the preliminary heating up of the furnace, loss by radiation, and other practical points. Actually, a much greater amount of heat is required to melt steel, say, from 6,000,000 to 9,000,000 B.Th.U. per ton in best practice, and about 12,000,000 B.Th.U. per ton in average practice; these figures relate to the open-hearth furnace. Thus, compared with a theoretical consumption of $\frac{4}{5}$ cwt. of coal per ton of steel melted, the actual consumption is from 4 to 6 cwts. in best

practice, and about 8 cwts. in average practice. Using electrical energy, about 2,200 lbs. of coal is consumed at the central station per ton of steel melted on the consumer's premises.

In this connection, reference may be made to the fact that the late Sir William Siemens, in his lecture to the Society of Telegraph Engineers (Vol. IX, 1880) on "The Dynamo Current in its application to Metallurgy," said that, with energy produced by the steam engine and passed through the dynamo, 1 lb. of coal is capable of melting about 1 lb. of steel. The prediction made by this great engineer has proved to be true for, during the year 1917, the author's firm melted about 31,800 tons of steel electrically with a coal consumption of about 31,800 tons.

With regard to the operation of the open hearth furnace as a thermal machine, comparatively few accurate heat balances have been published. Notably quite recently Mr. F. Clements, in this country, has dealt with this subject ; also Messrs. C. L. Kinney, and G. R. McDermott, in America, who were awarded by the American Institute of Mining and Metallurgical Engineers the prize offered by the author for the best paper on the conservation of fuel.

It is important to note that the fuel consumption of the open hearth furnace depends not only on its efficiency as a thermal machine, but also upon metallurgical considerations, which may have considerable effect. The best index of the heating efficiency of the melting furnace is naturally the rate of melting, expressed in tons per hour. Many comparisons are met with, in which the fuel efficiency of the furnace is given as an overall fuel consumption per ton of output. In such cases it is not always realised that the major circumstances determining good fuel ratios have been purely metallurgical, namely, such factors as the percentage of scrap in the charge, its composition, the size of the material charged, the manner of charging, and then the length and character of the refining period, and fettling time.

From observations on the melting efficiency of open hearth furnaces it may be said that such efficiency, based on the heat input to the furnace, varies from 20% to over 30% according to the size and character of the furnace, and the composition and character of the charge. The utilisation of the heat losses in the waste gases is a difficult problem in those cases where steam from waste heat boilers would be a useless by-product. These losses exceed 30% of the heating value of the fuel, and

there is a practical limit to their use in the regenerative system, though a certain proportion must be regarded as useful in a sense as it creates the chimney draught. The major portion of the radiation and conduction losses is from the working chamber itself and their reduction is a question of improved refractory materials and higher rates of heat transmission in the laboratory of the furnace. Careful control and improvement of producer conditions not only influence the producer losses within a range of 10% of the heat of the fuel, but also contribute a comparatively greater share towards the general efficiency of the plant.

The more recent developments in open hearth design have tended towards what amounts to harder driving, brought about by improved flame conditions as instanced by the McKune port which attempts to get a blow-pipe action on the surface of the bath.

In the higher temperature processes of melting furnaces temperature measurement is as important in its influence on both metallurgical and thermal considerations as in the lower temperature operations of the forge or heat treatment furnace.

The optical pyrometer, the technical application of which has made much progress in this field, is the chief scientific instrument. In actual practice, personal observation of the appearance of the metal, pouring and rod tests, largely hold the field as the means of heat control. In so far as the temperature of a molten bath is concerned, the last class of indications, i.e., the action of the bath on rods inserted and manipulated in a variety of ways, is generally favoured as the most reliable, and when the factors eventually come to be studied and the indications correlated to the thermometric scale, perhaps a scientific basis may be found for their use. At present the optical pyrometer must be the means for correlating that scale with these methods. Its value as an index of true temperature conditions depends upon the change of emissivity of the surface of the hot body. The question also as to whether "black body" conditions are being observed, for example, as to whether the door opening is modifying them, has to be considered. The solid angle subtended by the door opening at the point observed is a variable with different furnaces and conditions. Whilst the earlier values of Burgess for steel and slag emissivities in the absence of more complete data as to the effect of many variables have served a useful purpose, it is

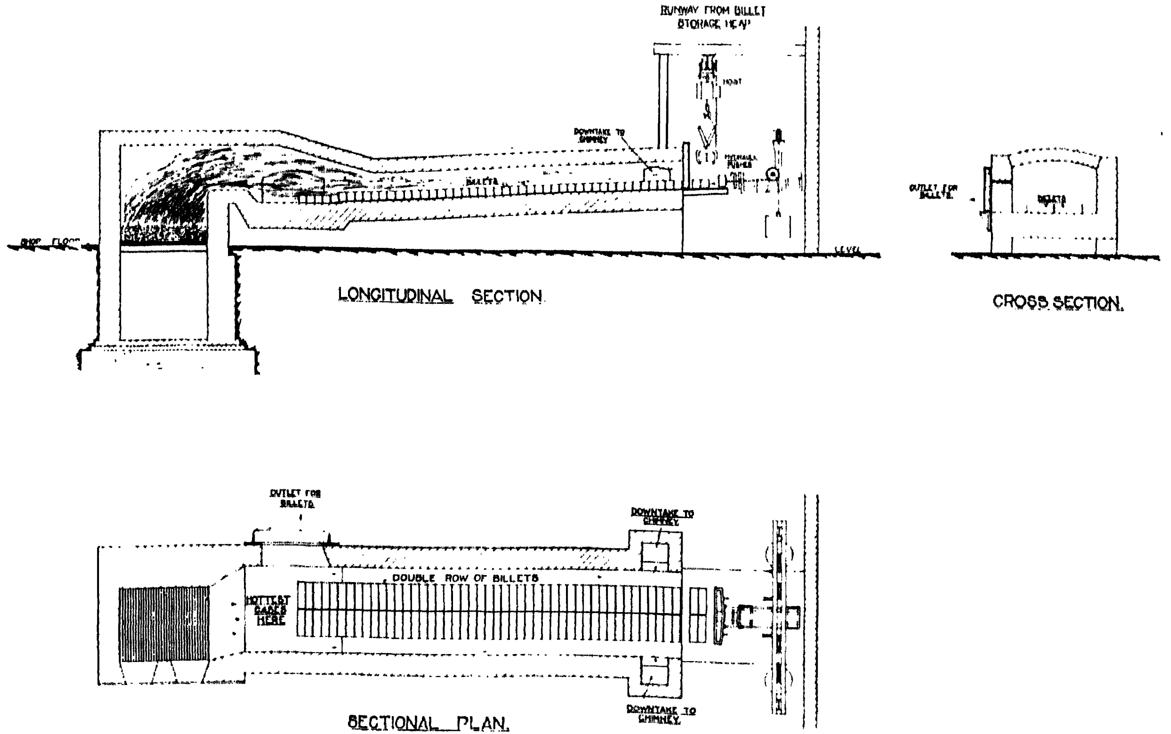
now being found that, in particular with regard to fluid slags and special steels the emissivity constants require revision.

Forge and Heat-Treatment Furnaces.—In furnaces of this type the measurement of temperature is an all-important factor. The metallurgical requirements demand almost rigid conditions of temperature distribution. This is also happily in the interests of fuel economy, going a long way towards reducing controllable operation losses.

Advances in this branch of fuel economy have in the past largely been on empirical lines—necessarily so by reason of the complicated character of the subject. In the design of the plant itself, progress has had to follow almost on lines of guesswork, each step having to be proved out under the confusing conditions of practice which often vary considerably from place to place. There is not always that close co-operation between the user and the designer that is necessary to enable the latter to take into account more precisely the influence of the many variable factors met with in practice. In recent years, however, notable efforts have been made to put the technology of furnace design and practice on a more rational basis. The pioneer work of Groume-Grjimailo dealing with the study of the flow of hot gases in furnaces is now becoming more generally known, and the leaven of this knowledge is working. The fundamental laws of the radiation, convection and conduction of heat are more or less understood, so are fundamental essentials in regard to gasification and combustion. The need of the moment is the application of this existing knowledge to the practical problems of the works.

As an instance of what can be accomplished in this direction it may be mentioned that certain new furnaces, put down hurriedly by the author's firm in the early days of the War, consumed at first as much as 0·75 ton of coal per ton of steel heated. This extravagant consumption was due to the fact that it had been impossible to pay sufficient attention to the construction and operation of the furnaces; also, much unskilled labour had to be accepted. After a time, however, the fuel consumption was reduced to 0·33 ton per ton of steel heated. This result was obtained with the same furnaces but with workmen taught the use of the damper and the proper method of firing.

With the Wincott continuous furnace, the consumption was further reduced to 0·1 ton of coal per ton of steel heated.



WINCOTT CONTINUOUS COAL FIRED REPEATING FURNACE.

As shown by Plate LVII, this furnace is automatic and continuous in action, billets being pushed continuously down the long sloping bed, and the hottest gases being at the opposite end from the cold billets. The coal consumption of only 0·1 ton per ton of steel heated from cold to 1,100° C. and well soaked, is an excellent result. In ordinary heating, 0·2 ton of coal per ton of steel heated has been considered quite good practice, and even at the present time probably represents the average when using the older types of coal-fired furnaces.

The author ascribes the excellent present practice of his firm to the fact that the Manager of this Department, Mr. W. E. Parker, has taken the trouble not merely to have the furnaces well handled, but also to give the workmen running this furnace special training of what may be termed a "technical" nature. In other words, the men have had a course of preliminary teaching which has enabled them to understand more fully the *rationale* of what they were asked to undertake. In consequence of this training, the workmen take an interest in their work and know why it is necessary to take pains with certain of the operations, the result being that the practical handling has proved very satisfactory.

Recuperation and Regeneration.—The main problem in any thermal machine is to develop the heat at the point at which it is required. However, in high temperature operation there must necessarily be a very high loss of sensible heat in the products of combustion coming from the furnace chamber calling for some preheating or regenerative device. The proportion of heat saved by the use of this principle can be deduced approximately by measuring the exit and entrance temperatures of the waste gases and air passing through the recuperative appliance. The additional effect of preheating of the combustion air in attaining higher calorific intensities and in saving heat by improved combustion conditions is less tangible but real.

The regenerator acting as a flywheel tending to smooth out those fluctuations of heating which are to be avoided in furnace heating, and serving as a reservoir of heat, can only achieve its maximum efficiency in continuous working. The question of the design and dimensions of these appliances has been the subject of much inquiry. More recently, mathematical solutions have been attempted, though it is realised that such methods can only serve to indicate lines of progress in so intricate a

subject. Again, thermal considerations are limited by other properties of the refractories to be used, such as refractoriness, mechanical strength and resistance to spalling, chemical corrosion and abrasion. It has also been realised that there are limiting dimensions and arrangements of chequer work beyond which it is not economically advantageous to go. Thus analytical study of the thermal properties of various classes of brick have shown that the " brick efficiency " depends upon the dimensions and times of reversal. For example, 95% saturation of a silica brick is attained in 15-minute reversals, and 20 minutes for fire brick under normal conditions. These figures apply to $2\frac{1}{2}$-inch bricks, whereas for 3-inch bricks the times become 20 and 30 minutes respectively. Provided it is practicable to measure the gas temperatures within required limits of accuracy, the proportion of heat recovered is given by the ratio of the temperature drop through the regenerator to the initial temperature of the ingoing heating gases, and the heat returned to the furnace by the rise in temperature of the heated air and a knowledge of the flow of gas and air. However, again the best thermal efficiency of the regenerative system may not be consistent with the best general efficiency of the furnace and its accessories as a whole. For example, a higher temperature of regeneration may only be attained at the expense of a higher outlet temperature of the waste gases. The point is well illustrated by the provision of waste heat boilers in the latest type of open hearth construction, as put forward by Clements in this country, and Kinney and McDermott in America.

The regenerator as usually constructed is a compromise between the demands of thermal and mechanical considerations, and it is for this reason that the orthodox methods of design have been more empirical than they might have been. Finally to cite but one line of development of considerable importance : whilst the influence of the velocity of the gases has been exhaustively studied in regard to heat transmission in boiler tubes, little is known of any definite quantitative character with regard to its significance in regenerator design.

Referring in particular to the recuperator, this is an appliance which should be capable of general application in furnace practice, but at present it is not because of the limitations in the thermal properties of the materials which may be used. Amongst the disadvantages which militate against their more extended use, are the relatively large bulk of material necessary

for a given heat recovery, and trouble arising from leakages, and short circuiting of the gases. The metal recuperator has its limitations for high temperature work, but with the development of non-scaling materials having suitable thermal characteristics at economic prices they should come into more general use.

National Promotion of Fuel Economy.—At the present time the advancement of fuel economy in this country is being assisted by the important work of the Fuel Research Board, as well as by the work of the Federation of British Industries, and the efforts which are being made by many firms to raise the thermal efficiency of their own fuel-consuming plant.

The Fuel Research Board.—During the late War the question of economy of fuel naturally became a problem of first importance. Under the joint stimulus of the Coal Conservation Committee and the Department of Scientific and Industrial Research, the Fuel Research Board was instituted by the Government in 1918 as a national research organisation for the study of fuel problems. The Board have since undertaken quite a wide field of useful enquiries, and have built at Greenwich a well-equipped station for practical experimentation.

Much credit is due to the late Sir George Beilby, F.R.S., the former Director of this Research Board, for his work in the past, including the "James Forrest" Lecture delivered by him in 1921 to the Institution of Civil Engineers on "Fuel Problems of the Future," which was of great interest and should most certainly be read by all those engaged in the study of the subject of fuel; also to the present Director of the Board, Dr. Landor, who is continuing the valuable work at the Greenwich Research Plant; and to Professor W. A. Bone, F.R.S., to whom the author has been specially indebted for much useful help and guidance in the direction of the scientific study of fuel economy questions.

The Federation of British Industries.—In this country, and as regards direct practical applications and improved methods, the Federation of British Industries took the lead by establishing a special department to furnish manufacturers with technical advice and assistance on fuel questions. The work of that department, which is now in the sixth year of its existence, has been devoted in the main to questions of steam raising and gas producer practice.

The Federation appointed in Dec., 1919, a Fuel Economy

Committee, of which the author is chairman. Under the guidance of its technical sub-committee, with Professor W. A. Bone, F.R.S., as chairman, ably assisted by Mr. G. W. Andrew, the technical assistant, and Mr. W. Prescott, considerable success has been achieved as the result of much devotion and attention in the carrying out of the programme of the Council.

The work already accomplished has been of an extensive and varied nature. Enquiries have been made into the more common errors of manipulation, major questions of development, and the more intricate matters dealing with accessories and control appliances. Research work of a general character has also been carried out on such problems as the generation of producer gas, the efficiency of boiler and steam pipe lagging, and methods of effecting fuel economy.

The Federation also publishes the *Fuel Economy Review*, which is specially devoted to disseminating knowledge and fostering interest in the subject.

Finally, an important function of this organisation has been the help that it has been able to give manufacturers in facilitating the interchange of relevant statistics.

It is also of interest to note that the National Federation of Iron and Steel Manufacturers has followed the lead given by the Federation of British Industries in putting into active operation a Fuel Economy Department. A Technological Fuel Committee has been established and is at the present time examining in detail Blast Furnace Practice with Coke Ovens as a corollary. The work is carried out by Mr. Edgar Evans under the guidance of a Technical Committee.

PART IV—EDUCATION AND RESEARCH.

CHAPTER XII

THE RISE OF EDUCATION AND RESEARCH.

Interdependence of Education and Research.—It will be seen clearly from the following paragraphs, if indeed it is not already self-evident, that in the scientific field education and research are inextricably associated. With few, if any, exceptions, successful research work must be based upon the wide and deep foundations of a liberal education, whilst education in the fullest sense of the word can only be obtained by research. Thus there is every justification for treating under one main heading the general needs of to-day in regard to education and research, and for giving some notable examples of what is being done by different Institutions, Societies, and other bodies, to encourage the growth and diffusion of knowledge. Upon this, to a greater extent perhaps than upon any other single factor, depends our prosperity and general well-being as individuals and as an Empire.

One of the principal applications of education must ever be to the elucidation of further knowledge and, whilst the utilitarian purpose of education is to enable us to earn a living which by research we may improve, the best and highest aim of research is the discovery of truth regardless of every other consideration. In his interesting paper on " A National Focus of Science and Research " the author's friend, Dr. G. E. Hale, Director of Mount Wilson Observatory, and Chairman of the National Research Council of America, says that it is not only in the material world that science is useful to mankind. Its greatest aim and object is the discovery of truth, which it pursues without fear of embarrassing consequences. Science sets before us a high example of honest judgment and an open mind, reversing its conclusions without hesitation when new evidence demands. And as it builds up through the centuries, by long and painful search, a great body of knowledge for universal benefit, it spreads before the imagination a picture which no artist could

hope to rival. No material service of science to daily life, such as the accurate marking of time or the navigation of the seas, can compare in value with its overthrow of earth-centred mediævalism and its revelation of the universe. The enlarged conception of human possibilities thus afforded, the escape thus effected from the dominance of enforced and arbitrary thought, are reflected in the advance of the modern world. And the sweeping picture that science spreads before us is unmatched in its appeal to the imagination and its stimulus to progress.

On the other hand, it ought not to be considered sufficient only to discover truth and only to make discoveries in "pure science." In the past we have undoubtedly erred in this direction and it needed the War to bring home to us the unpleasant fact that we had allowed other countries to acquire a predominant position in the development of certain key industries, though the basic discoveries, on which these industries were based, had been made by British scientists. Such an illogical and even dangerous state of affairs is not compatible with our national reputation for practical common-sense and it is to be hoped that, whilst we continue to make truth the first aim of our investigations, we shall in every case carry our discoveries to industrial fruition.

Early Academies.—Whilst the specialised knowledge required by chemical, metallurgical, and engineering students when entering upon their professional career demands close attention to the facts and figures relating to modern progress, there is much to be learned from a study of the history of progress in science. The birth of modern science has already been outlined in Chapters I to III, and before proceeding to review present-day facilities for education and research it will be of interest to deal briefly with the events which preceded the foundation of the Royal Society, and then with the history of that great Society which has played such an important part in encouraging and spreading the growth of knowledge.

The first society instituted for the investigation of physical science was that established at Naples in the year 1560 with the name of Accademia Secretorum Naturæ, but its studies were prematurely brought to a close, the Academy having been dissolved by the Ecclesiastical authorities.

The important Accademia del Cimento published reports of experiments made by its members in 1666. Amongst these

Castellio and Torricelli, disciples of Galileo, were the most illustrious; to them are due many of the discoveries in the science of hydraulics; whilst the invention of the barometer alone renders the name of Torricelli immortal. He made this discovery in 1643; and in 1648 Pascal, by his celebrated experiment on the Puy de Dome, established the theory of atmospheric pressure beyond dispute.

It was about this time, 1636, when a very curious and scarce tract entitled *The Constitutions on the Museaum Minervæ* was published, relative to the attempt made to establish a Scientific Institution under the patronage of Charles I, who in the eleventh year of his reign granted a Special Licence under the Privy Seal, dated at Canbury June 26th, 1635, to establish a College or Academy under the title of Minerva's Museum, for the instruction of the young nobility in the liberal arts and sciences. The aristocratic tendency of the Institution may be judged by its first rule, namely: "Every man that shall be admitted into the said Museaum shall bring a testimoniall of his arms and gentry, and his coate armour tricked on a table, to be conserved in the Museaum." The College was to be erected in Covent Garden; the Professors selected and their duties were as follows:

Edward May Doctour of Philosophie and Physick shall reade and professe these: Physiologie, Anatomie, or any other parts of Physick.

Nicholas Phiske the Professour of Astronomie shall teach these: Astronomie, Opticks, Navigation, Cosmographie.

John Spidell the Professour of Geometrie shall teach these: Arithmetique, Analyticall Algebra, Geometrie, Fortification, Architecture.

Thomas Hunt the Professour of Musick shall teach these: skill in Singing, and musick to play upon Organ, Lute, Violl, and other instruments.

Walter Salter the Professour of Languages shall teach these: Hebrew, Greek, Latine, Italian, French, Spanish, High Dutch.

Michael Mason the Professour of Defence shall teach these: Skill at all weapons and wrestling, also Riding, Dancing and Behaviour.

As Dr. Weld says in his "History of the Royal Society," to which the author is indebted for much useful information: "The time was too unsettled to allow so fair a project to ripen, and it is almost needless to state, that Minerva's Museum never attained its contemplated greatness."

France was also moved to follow the stirring example of Italy, and the French Academy was established, springing from a private society of men of letters at Paris in the year 1629. This institution was subsequently incorporated with the Academy of Sciences and that of Inscriptions and Belles Lettres. Although France thus early founded a society for the cultivation of literature, yet to England belongs the high honour of being the first country, after Italy, to establish a society for the investigation of Physical Science. The period had arrived when experimental philosophy, to which Francis Bacon had held the torch, and which had already made considerable progress, specially in Italy, was finally established on the ruins of arbitrary figments and partial inductions.

The Royal Society. The first real development in the study of science in this country appears to have occurred during the seventeenth century. It was marked—and to a great extent fostered—by the formation of the Royal Society. The Charter of Incorporation of this famous Society, marking the commencement of its great work, passed the Great Seal on the 15th July, 1662. It was read before the Society on the 13th August of the same year, and on the 29th, the President, Council, and Fellows went to Whitehall in order to return their thanks to His Majesty King Charles II.

Previous to the Charter being granted, a Meeting had been held on the 5th December, 1660, and the Signatures are extant of the forty-one persons who on that date resolved to form the Society for promoting Experimental Philosophy.

At every Meeting of the Council and of the Society since its foundation, the Mace, " of the same fashion and bigness as those carried before His Majesty," presented to the Society by Charles II in May, 1663, as a mark of the Royal Favour, is laid on the table in front of the President before the business of the day is begun. This Mace weighs one hundred and fifty ounces (Troy weight). It is of silver, richly gilt, and consists of a stem handsomely chased with a running pattern of roses and thistles, terminated at the upper end by an urn-shaped head, surmounted by a crown, ball and cross. On the head are embossed figures of a rose, harp, thistle and fleur-de-lys, emblematic of England, Ireland, Scotland and France, on each side of which are the letters C.R. Under the crown, and at the top of the head, the Royal Arms appear very richly chased; and at the other extremity of the stem are two shields,

the one bearing the Arms of the Society and the other an inscription.

Without doubt the foundation of the Royal Society was one of the earliest fruits of the philosophical labours of Francis Bacon, whose great aim was to enforce patient investigation of Nature by observation and experiment, as compared with the deductive method which till then had been in vogue.

Singular to say, Bacon seems to have been unable himself to admit that the inventions and investigations made before his time were due to science, but regarded them as happy accidents of chance. In this respect he was, for example, wrong to ignore Gilbert's great scientific work on Magnetism, which was published in 1600 before the earliest of Bacon's Philosophical Treatises.

Dr. Gough in the excellent preface to his edition (1915) of *The New Atlantis* of the great Francis Bacon, Lord Verulam, Viscount St. Alban (Plate II), first published in 1627, that is the year after his death, points out the great services to the cause of science rendered by Bacon. His life work was to advocate philosophical and scientific reform. He claimed "that the sovereignty of man lieth hid in knowledge; wherein many things are reserved which Kings with their treasures cannot buy nor with their force command."

In one of Bacon's contributions he stated that he had looked round to find in what way he could best serve mankind and that he found "There was none so great as the Discovery of new Arts, Endowments and Commodities for the bettering of man's life." Also, "But if a man should succeed, not by striking out some particular Invention, however useful, but in kindling a light in Nature, a light that should in its very rising touch and illuminate all the border regions that confine upon the circle of our present knowledge; and so spreading further and further should presently disclose and bring into sight all that is most hidden and secret in the world—I thought that man would be the benefactor indeed of the human race—the propagator of man's empire over the universe, the champion of liberty, the conqueror and subduer of necessities."

As Dr. Gough points out, Bacon was not content with explaining to the learned world the method which he believed would revolutionise Science; he was eager to "set the machine on work." In some secret memoranda, the *Commentarius solutus*, which he jotted down in the summer of 1608, he stated that he proposed to superintend the compilation of a History of

Marvels, *i.e.*, of apparently abnormal phenomena, and a History of Mechanical Inventions. He included the foundation of a College for inventors ; two Galleries with statues for inventors past, and spaces or bases for inventors to come ; and a Library and an Enginary. The *Novum Organum*, that is "The New Instrument" (published in 1620) represented the mature presentation of his system. This "New Instrument" is contrasted with the old instrument for the attainment of knowledge, the syllogistic logic of Aristotle and his mediæval disciples.

Bacon showed "that we can only gain power over Nature and make her serve our purposes by discovering and imitating her modes of action." "Parendo vincitur." He showed that it was not enough to proceed by the blind and stumbling empirical methods hitherto in vogue, but that we must examine the instances we have collected to find the formal cause of that nature, or in Bacon's technical language, its "form." These "forms" are, as Bacon observes, the laws which govern and constitute simple natures.

It was in *The New Atlantis* of Bacon, left when he died in 1626, and which should be read by all, that he foreshadowed the future, the main feature of this being Solomon's House, "a Philosophical College," which was the embodiment of his life-long dream, and really the forerunner and a prophetic scheme of the foundation and work of the Royal Society that was to be. His projected College was to consist of a Company of thirty-six "Fellows," this being the word chosen and used by Bacon, and this appellation has continued ever since.

The history of the Royal Society's earliest work has been set forth in several books, one of the first and most interesting being *The History of the Royal Society of London for the Improving of Natural Knowledge*, written in 1667 by Thomas Sprat, D.D., the Lord Bishop of Rochester. Plate LVIII shows the engraving by Hollar in 1667, used as the frontispiece to Sprat's book. The bust in the centre of the engraving represents King Charles II, the figure on the right Francis Bacon, and that on the left Lord Brouncker, the first President of the Royal Society. It will also be noticed that various instruments and pieces of apparatus are shown on the engraving. The author referred the question of their identity to the expert opinion of his friend, Dr. Charles Singer, F.R.S., the distinguished authority on the history of science. Dr. Singer has been able to identify

The Bust in the centre of the Engraving represents King Charles II, the figure on the right Francis Bacon, and that on the left Lord Brouncker, the First President of the Royal Society.

From an Engraving by W. Holler in the Book by Thomas Sprat, D.D., F.R.S., Lord Bishop of Rochester, entitled "The History of the Royal Society of London for the Improving of Natural Knowledge," published in 1667.

PLATE LIX

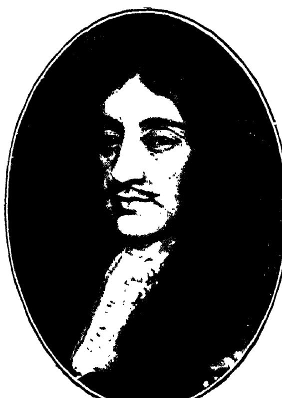
THE FOUNDER, AND SOME OF THE PAST NOTABLE FELLOWS OF THE ROYAL SOCIETY.

(Most of these are given by kind permission of the Council of the Royal Society.)

SIR HUMPHRY DAVY
1778-1829

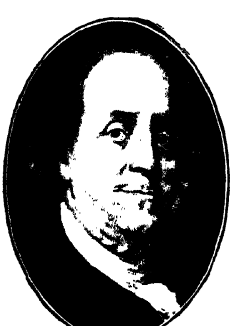
MICHAEL FARADAY
1791-1867

SIR ISAAC NEWTON
1642-1727

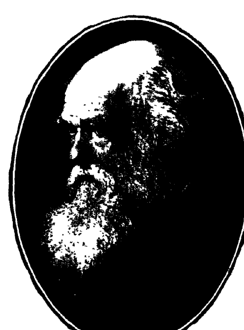


CHARLES II.
The Founder
1630-1685

SIR CHRISTOPHER WREN
1630-1723



BENJAMIN FRANKLIN
1706-1790



CHARLES DARWIN
1809-1883

on the left of the engraving an instrument for taking the angular distance between two objects and another which was used for measuring the altitude of stars. A clock and a gnomon are also easily distinguishable, whilst a telescope is visible in the background. On the right of the engraving is a thermometer of the type invented about 1600 by Sancto Sanctorio, and a compass, below which is an instrument that can be no other than a theodolite. Two adjustable pendula are also shown. There are also four or five other instruments, the exact nature and use of which are uncertain. On the opening page of the book, the following words appear : " Let this Book, Intit'led, The History of the Royal Society of London, for the Improving of Natural Knowledge, be Printed. Will. Morrice."

" The Epistle Dedicatory," as my Lord Bishop terms it, is so fascinating that it may be quoted at some length.

The Dedication was To The King, Charles II (1630–1685), and ran as follows :

> " Sir,—Of all the Kings of Europe, Your Majesty was the first, who confirmed this Noble Design of Experiments, by Your own Example, and by a Public Establishment. An Enterprise equal to the most renouned Actions of the best Princes. For, to increase the Powers of all Mankind, and to free them from the bondage of Errors, is greater Glory than to enlarge Empire or to put Chains on the necks of Conquer'd Nations.
>
> " What Reverence all Antiquity had for the Authors of Natural Discoveries, is evident by the Diviner sort of Honor then conferr'd on them. Their Founders of Philosophical Opinions were only admired by their own Sects. Their Valiant Men and Generals did seldome rise higher than to Demy-Gods and Hero's. But the Gods they worshipp'd with Temples and Altars, were those who instructed the World to Plow, to Sow, to Plant, to Spin, to build Houses, and to find out New Countries. This Zeal indeed, by which they expressed their Gratitude, to such Benefactors, degenerated into Superstition ; yet it has taught us, That a higher degree of Reputation is due to Discoverers, than to the Teachers of Speculative Doctrines, nay even to Conquerors themselves.
>
> " Nor has the True God himself omitted to show his value of Vulgar Arts. In the Whole History of the first Monarchs of the World from Adam to Noah, there is no mention of their Wars, or their Victories ; all that is recorded is this, They liv'd so many years, and taught their Posterity to keep Sheep, to till the Ground, to plant Vineyards, to dwell in Tents, to build Cities, to play on the Harp and Organs, and to work in Brass and Iron. And if they deserved a Sacred Remembrance, for one Natural or Mechanical Invention, your Majesty will certainly obtain Immortal Fame, for having Establish'd a perpetual Succession of Inventors.—I am, (May it please Your Majesty), Your Majesty's most humble and most obedient Subject and Servant, THO. SPRAT, Lord Bishop of Rochester."

Quaint as may seem these words to us to-day, there is indeed still as much force and truth in them as when they were uttered. The marvellous recent progress of the world has been largely due to the scientist, who certainly comprises the inventor referred to by Bishop Sprat, and not least in these branches of human thought are those who work in "Natural or Mechanical Inventions" or, to use again the Bishop's words, "In Brass and Iron," though the latter metal nowadays plays much the more prominent part.

The qualifications of the Members of the Royal Society are described by the Bishop as follows:

> "As for what belongs to the Members themselves, that are to constitute the Society; it is to be noted that they have freely admitted Men of different Religions, Countries, and Professions of Life. This they were oblig'd to do, or else they would come far short of the largeness of their own Declarations. For they openly profess, not to lay the Foundations of an English, Scotch, Irish, Popish, or Protestant Philosophy, but a Philosophy of Mankind . . . To this purpose, the Royal Society has made no scruple, to receive all inquisitive strangers of all Countries into its number. And this they have constantly done, with such peculiar respect, that they have not obliged them to the charge of contributions; they have always taken care, that some of their Members, should assist them in interpreting all that pass'd, in their publick Assemblies: and they have freely open'd their Registers to them; thereby inviting them to communicate foreign Rarities, by imparting their own discoveries. By their admission of Men of all professions, these two benefits arise: The one, that every Art, and every way of life already establish'd, may be secure of receiving no damage by their Counsels. A thing which all new Inventions ought carefully to consult."

On November 20th, 1663, the Royal Society, according to MS. preserved in the British Museum, consisted of 131 Fellows, of whom 18 were Noblemen, 22 Barons and Knights, 47 Esquires, 32 Doctors, 2 Bachelors of Divinity, 2 Masters of Art and 8 strangers or foreign Members.

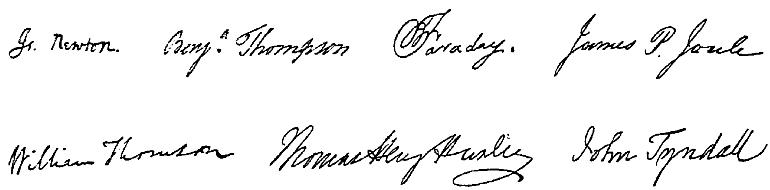
Since then the number of Fellows has increased and is now 456. Each year the Council selects from the List of Candidates a number not exceeding fifteen to be recommended to the Society for election.

The Charter Book, which each Fellow must sign before being admitted into the Society, goes back to the year 1660. It is preserved in the Archives of the Society and is used each time a Fellow signs the Charter. In this same Book are to be found the signatures of King Charles II (the Founder), his brother, the Duke of York (afterwards King James II), and the signatures

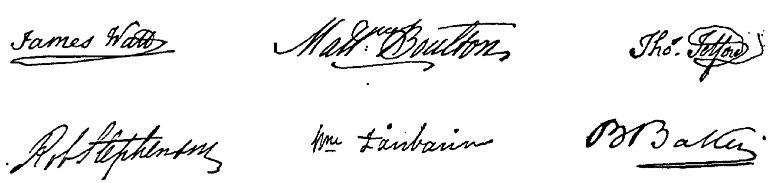
SIGNATURES OF SOME OF THE PAST NOTABLE FELLOWS OF THE ROYAL SOCIETY, COLLECTED FROM DIFFERENT PAGES OF THE CHARTER BOOK.

(By kind permission of the President and Council of the Royal Society.)

PHYSICISTS



ENGINEERS



The signatures are half full size.

CHARLES II.
Founder and First Fellow of the Royal Society, 1664.

JAMES (DUKE OF YORK)
Second Fellow 1664, and afterwards James II.

LORD BROUNCKER
The First President of the Royal Society 1663.

PHYSICISTS

ISAAC NEWTON
Discoverer of the Law of Gravitation 1671

BENJAMIN THOMPSON
Afterwards Count Rumford. Founder of The Royal Institution, and the Rumford Medal 1779.

MICHAEL FARADAY
Discoverer of the Laws of Electrical Induction 1824.

JAMES P. JOULE
First to accurately measure the Mechanical Equivalent of Heat 1850.

WILLIAM THOMSON
Afterwards Lord Kelvin. Very eminent Physicist and Mathematician 1851.

THOMAS HENRY HUXLEY
Biologist, Philosopher and Man of Letters 1851

JOHN TYNDALL
Distinguished Experimentalist and brilliant writer 1852

ENGINEERS

JAMES WATT
Inventor of the Steam Engine 1785

MATTHEW BOULTON
Eminent Engineer and Co-partner with Watt 1785.

THOMAS TELFORD
The First President of the Institution of Civil Engineers in 1820. Effected great advances in road construction 1827.

ROBERT STEPHENSON
Distinguished Engineer 1849

WILLIAM FAIRBAIRN
Designer of the Menai Straits Bridge 1850

BENJAMIN BAKER
Designer of the Forth Bridge 1890

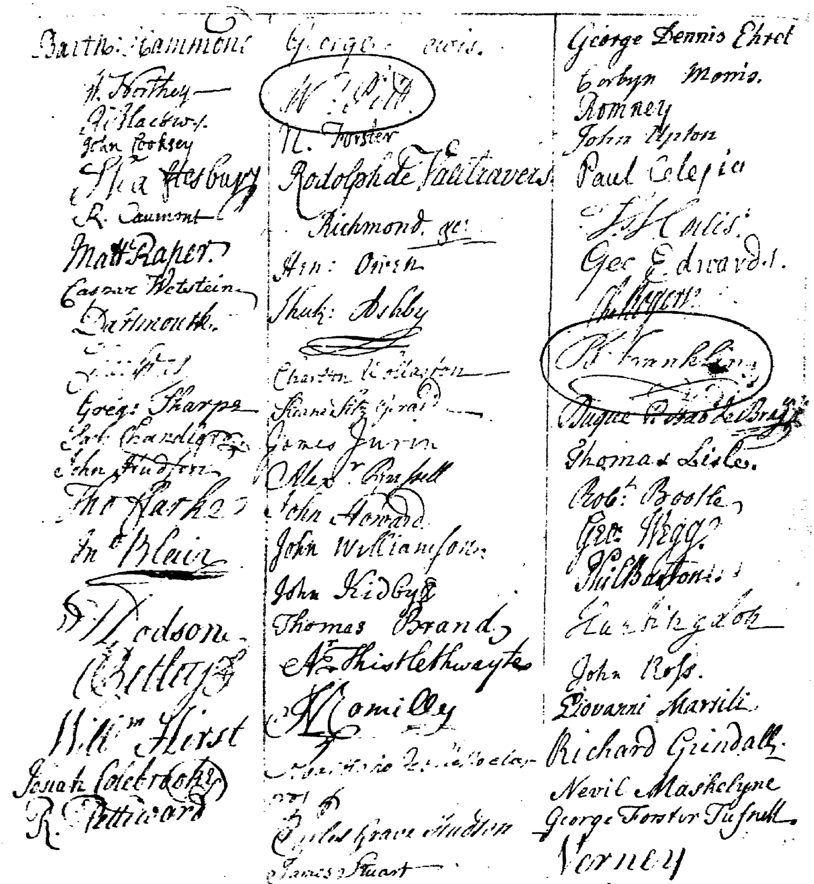
The date affixed to each name represents the year in which the Charter of Fellowship was signed.

FACSIMILE OF ONE OF THE PAGES OF THE CHARTER BOOK OF THE ROYAL SOCIETY.

From the Incorporation of the Society in 1662 down to the present time each Fellow has subscribed to the following Obligation, and has signed his name in this Charter Book.

The Obligation of the Fellows of the ROYAL SOCIETY.

WE who have hereunto subscribed, do hereby promise, each for himselfe, that we will endeavour to promote the Good of the Royall Society of London for improving Naturall Knowledge; and to pursue the Ends for which the same was founded; That we will be present at the meetings of the Society, as often as conveniently we can, especially at the anniversary Elections, and upon Extraordinary occasions; and that we will obserue the Statutes and Orders of the said Society. Provided that whensoever any one of us, shall signify to the President, under his hand, that he desireth to withdraw from the Society, he shall be free from this Obligation for the future.



The signatures are half full size.

The above are the Signatures (on Page 27 of the Charter Book) of Fellows between the years 1754-1758. Attention is called to the two notable and historic signatures in the ovals, namely, those of William Pitt, afterwards Earl of Chatham, and Benjamin Franklin.

of nearly all our Royal Heads down to the present time. It also contains the signatures of the great scientists of the past, including the first President of the Society, Lord Brouncker, Cavendish, Robert Boyle, Wren, Evelyn, who were all original Fellows, elected on the 22nd April, 1663; Newton (11th January, 1671), Benjamin Franklin (29th April, 1756), Priestley (12th June, 1766), Davy (17th November, 1803), Dalton (20th June, 1816), Faraday (8th January, 1824), Wheatstone (21st January, 1836), Louis Agassiz (20th December, 1838), Duke of Wellington (25th November, 1847), William Harvey (3rd June 1858).

In Plates LIX, LX, and LXI will be found portraits and facsimile signatures of some of the most notable Fellows, including Charles II, James II, Franklin, Pitt, Shaftesbury, Jurin (the Secretary of the Royal Society at that time), Nevil Maskelyne (one of the famous Astronomers Royal), Isaac Newton, Faraday, Joule, Thomson (afterwards Lord Kelvin) Huxley and Tyndall.

It is curious to note on Plate LXI the wonderful flourishes and curves on Benjamin Franklin's signature, apparently proceeding from the last letter of his name. To a caligraphist this probably betokens some special mental characteristic. The total length of the flourish is exactly nine inches!

The interesting statements about the Society by Bishop Sprat and others show that, whilst the years roll by, the minds of men, naturally modified by the environment of each particular age, still remain much as they were. Since the date when the wise words of the Bishop were written, the Royal Society has had one long-continued career of usefulness, and owing to the devotion of its Fellows to the cause of science and scientific progress, mostly without reward of any kind, there is no country where science and scientific work are more highly esteemed than in Great Britain, though America has rightly followed our lead and bids fair to surpass us. It is often said that we lack appreciation of scientific merit, but this is not correct. The fight for the cause of advance and progress may at times be severe and difficult, but in the long run, the author ventures to think, Britons and Americans more fully recognise true scientific merit than any other race.

It is now 263 years since the incorporation of the Royal Society, yet the influence of Bacon and such men as Sprat was in the same direction as ours to-day, that is, to improve human

conditions, both mental and physical. This can only be done little by little, line upon line, precept upon precept; by improving our mental philosophy and striving to reach higher and still higher in human thought and its application to our lives.

CHAPTER XIII

EDUCATIONAL METHODS AND FACILITIES.

Modern Educational Facilities.—At the present time the educational facilities of this country range from books and museums to Universities and technical classes covering all known subjects. It has been customary for some, even in high quarters, to decry our educational training, but those who argue thus appear to overlook the fact that this country has led the way in all branches of science and engineering. Our educational system has doubtless, like every other human organisation, its defects and its limitations, but neither in the achievements of our past workers in science and engineering nor in the standing and rate of progress of our living workers, are there any grounds for pessimism. On the contrary there is ample justification for the optimism and inspiration which are so essential to progress and success.

In his Presidential Address to the Society of British Gas Industries in 1918, the author pointed out that in the British Empire there were 60 Universities, 233 Colleges, and 44 Technical Schools. These numbers compared with 98 Universities and 16 Technical Schools in the United States. France had 16 Universities, Italy 22 Universities, Austria-Hungary 11 and Germany possesssed 21 before the War. Though there have been some changes in these figures during recent years, the favourable position of our Empire is well maintained. As regards the teaching staff in the Universities, including the Heads, Professors, Lecturers, Demonstrators, and Trained Assistants, it is believed that there not far short of 10,000 in the British Empire.

The Purpose of Universities.—The true function of every established University can be summarised in a few words. It is surely the inculcation of higher and broader education than is obtainable by other means. In the words of His Majesty the King, responding to the Address from the University of

Manchester on the occasion of his visit to that city in July, 1913: "It is to the Universities that the whole Empire looks for men equipped with scholarship and technical knowledge, with will and energy, devoting their gifts to the service of the community in every sphere of action."

Whilst, as Lord Rosebery said not long ago, some appear to succeed in life without any form of academic discipline, yet, on the other hand, we have the remarkable testimony of probably the greatest man in the War, Marshal Foch, who, when asked whether he found his academic studies to be of any immediate service on the field of battle, said: "No, not altogether, but they give me confidence." It is this confidence in life which is so important and so absolutely essential—the quiet confidence which comes from knowledge, and knowledge is Power.

University education and aid are of the highest importance, but do not necessarily imply actual study by those who benefit at the seat of learning; in many cases it is rather the influence always silently at work upon the great mass of human beings outside their sphere. It is true that in every generation since the Renaissance "self-educated" men have risen to eminence, but in every instance they have been favoured by circumstances or by unusual natural ability. Also, many of these men have attained eminence without scholarship. Confining ourselves to those who ultimately became leaders of thought and wideners of the boundaries of knowledge, is there one who would not have done more and better with the aid of a University education in the present meaning of the term?

It might be said that Faraday, first the bookbinder's apprentice and ultimately the foremost scientist of his age, was self-educated, but he had in the Royal Institution itself at the feet of Sir Humphry Davy a University education in all but name.

A notable member of the Labour Party recently said, evidently without due thought, that "Labour did not need Oxford, and that if a man was able to read, all that he needed was to take up a book, and then he could get the higher education without the necessity of going to a University with an old Tory tradition." Apart from the fact that, as pointed out by Lord Haldane, "only the trained mind can reach the level of higher education," it must be admitted that books, which enable the industrious to dispense with University tuition, must be written by University men. Abolish

Universities and the level even of general education would quickly, and with increasing rapidity, fall below the level of that in countries which still maintained these institutions as centres and birthplaces of learning.

All cannot, and need not, be members of a University, but every University renders invaluable and irreplaceable service to the whole of the community.

The Old Order Changeth.—Though the older Universities remain and will remain as essential as ever to the welfare and progress of our Empire, their duties are naturally changing as the field of knowledge extends. Science, of which we were virtually ignorant a century ago, now finds application in every phase of our daily life, and so great a change cannot fail to have all-pervading effects.

The late Sir William Osler, Bt., M.D., F.R.S., President of the Classical Association, Regius Professor of Medicine, had much to say on the great advances in thought made in his own time. His address on "The Old Humanities and the New Science," already mentioned in Chapter I, may be read again and again with pleasure and profit, and should be studied by all those interested in scientific matters.

In outlining the progress made within the memory of many still living, Sir William said:

> "Think of the Cimmerian darkness out of which our generation has, at any rate, blazed a path! Picture the mental state of a community which could produce Omphalos—an attempt to untie the geological knot. I heard warm clerical discussions on its main thesis, that the fossils there referred to were put into the earth's strata to test men's faith in their belief of the Mosaic account of the Creation, and our Professor of Natural Theology lectured seriously upon it!
>
> "An age of Force followed the final subjugation of Nature. The dynamo replaced the steam engine, radiant energy revealed the hidden secrets of matter, to the conquest of the earth was added the control of the air and the mastery of the deep. Nor was it only an age of Force. Never before had man done so much for his brother. The victory over the powers of Nature meant also glorious victories of peace; pestilences were checked, the cry of the poor became articulate, and to help the life of the submerged half became a sacred duty of the other. How full we were of the pride of life!"

Whilst it is not intended to present matters for controversial discussion, many will agree heartily with the line of thought taken up by Sir William Osler, when he said:

> "The Humanities have been a subject of criticism in two directions. Their overwhelming prominence, it is claimed, prevents

the development of learning in other and more useful directions; and the method of teaching is said to be antiquated and out of touch with the present needs. They control the academic life of Oxford. An analysis of the Register for 1919 shows that of the 257 men comprising the Heads and Fellows of the twenty-three Colleges (including St. Edmunds Hall), only 51 are Scientific, including the Mathematicians."

No doubt since then Oxford has made great strides in the encouragement of science and its study.

University Training in Metallurgy.—In a valuable paper on "Metallurgical Education of University Rank in Great Britain," presented to the Empire Mining and Metallurgical Congress in 1924, Professor H. C. H. Carpenter, F.R.S., gave a concise account of the facilities for metallurgical education and research in this country. This contribution shows that we lead, and do not follow, in this branch of science. In the principal Universities of the United Kingdom there are a dozen important departments of metallurgy, each with its own special character. Every branch of the subject is now represented so that, as suggested by Professor Carpenter, any further resources which may become available for education and research in metallurgy should be devoted to strengthening and extending existing departments rather than to founding new ones.

The problem as to what courses should be included in a University training in metallurgy has aroused much controversy. Useful information bearing upon the subject is to be derived from the report of the Inter-University Metallurgical Conference arranged by the University of Birmingham in 1923 and attended by fifty delegates and representatives from London, Birmingham, Sheffield, Leeds, Cardiff, Manchester, and Glasgow.

A wide variety of opinion was expressed. Some of those who took part in the discussion considered that, in addition to metallurgy itself, mathematics was the best subject with which to train students' minds; others held that chemistry and physics were the most important subjects, and some that economics, book-keeping and psychology should not be overlooked. It is not easy to determine the exact curriculum which suits the mind of each particular individual. No doubt a general combination of the subjects, in so far as time will permit, is best. In any case, mental training on any one of the several subjects must be of great service, and it is specially important that "character" and powers of observation be developed. It

is astonishing how unobservant are some individuals simply for want of training that particular faculty.

The conclusions reached by this important Conference deserve to be reproduced; they were as follows:

1. That the pure Sciences of Mathematics, Physics, Chemistry and Physical Chemistry are of the greatest importance and should be given a large part in a Metallurgical course. This was carried unanimously.

2. That specialisation is undesirable during training and should be left until after graduation. This was carried with one dissentient.

3. That the vacations at Christmas and Easter should be shortened, if necessary, to allow at least two months being put in at works during the summer. This was carried unanimously.

4. That an adequate training in a second modern language should be included in a Metallurgical course. This was carried with three dissentients.

5. That the Conference emphasised the importance of a University Metallurgical Society to the student in his work. This was carried unanimously.

6. That it is desirable to include, if possible, a course of industrial economics in a course of Metallurgy. This was carried with one dissentient.

7. That no course is complete, unless in his final year the student takes an interest in modern research. This was carried unanimously.

8. That the true function of a University is to produce sound citizens. This was carried unanimously.

In this and every other civilised country there is an increasing realisation of the value of University degrees as the "hall-mark," not of wealth or social position, but of knowledge and training, also of the culture and moral fibre which such training entails. The non-residential Universities of our industrial cities, and even the historic Universities of Oxford and Cambridge, are now open to students of all classes, thanks to the many scholarships which have been founded.

The Scope and Importance of Chemistry To-Day.—It is now generally realised how varied and important are the services rendered by chemists to those who work in every branch of applied science, including metallurgy, and the many divisions of engineering. Indeed, it is difficult to exaggerate the part played by the chemist in modern industries of almost every description, and it is steadily becoming more widely recognised that chemical analysis and supervision are of the utmost importance to the technical perfection and commercial success of industries which, at first sight, may appear to have nothing of a chemical nature in either their products or their requirements. In almost every instance, however, analysis of raw

materials, intermediate products, and finished materials offers great opportunities for improving and cheapening production.

In the metallurgical field, chemistry is naturally of fundamental importance, and the chemist's work is arduous and exacting. In making his analyses he has often to perform a long sequence of operations, each requiring great care, and the slightest failure or inaccuracy in any one of these will completely vitiate the final result. There can be no "cooking" of figures; accuracy must reign supreme.

British Chemists to the Fore.—A point to which the author has referred on other occasions at greater length—and must again mention for the sake of justice—concerns the vaunted superiority of German chemists.

We have had so many brilliant chemists in our national life that it is difficult to understand why the Teutonic chemist has been held up to such glory. Robert Boyle, termed the Father of Modern Chemistry, has an imperishable memory. Then we have Roger Bacon, Black, Cavendish, Priestley, Davy, Wollaston, Faraday, Playfair, Roscoe, Graham, Abel, Crookes, Ramsay, Dobbie, Soddy, Bragg, Rutherford, Perkin, Thorpe, Armstrong, Abney, Jackson, Tilden, Dewar, Beilby, Meldola, Dixon, Scott, Pope, and others. No nation can outvie this list, and certainly not Germany.

The truth is that by commendable diligence and industry, and by a much less praiseworthy policy of persistent propaganda, the Teuton gained more credit than he deserves as regards fundamental discoveries and developments. We have only to call to mind such names as Ramsay, Dewar, and Perkin, three of the world's greatest chemists.

In saying this, it is not meant to imply that Germany has not done, and will not do, her share in helping to advance knowledge. Nevertheless, whilst Germany has performed useful work in the past, there is no reason why German chemistry should be allowed that world-wide domination, which was the object of her pre-war policy.

The author received much help in his earlier days from the useful books of Fresenius on Chemistry, and also enjoyed a friendship of long standing with the famous German chemist, Professor A. Ledebur, for many years head of the Freiburg School of Mines and Chemistry, from which so many useful chemists have been turned out.

For many years the author corresponded with Ledebur and

always found his views upon the perplexing question of the nature of carbon compounds in iron and steel sound and most useful. His excellent papers to the Iron and Steel Institute were helpful to all of us. Ledebur's work helped to keep the author's mind, and no doubt that of others, clear from the taint of the allotropic heresy, which has been rejected, thanks largely to the great opposition of Sheffield and its metallurgists.

Ledebur was an honest seeker after the truth, and the following words, from a little book entitled "Adolf Ledebur, his Life and Work," may well be taken to heart:

> "A wide acquaintance and a broad life; Long years of honest endeavour; Always investigating and always well-founded; Never close in thought but always plain and open; Preserving the truth of the old; Receiving the new in a friendly spirit; A noble mind and a pure aim; Death comes well to such a man."

In a recent interesting letter from one of our highest authorities, Sir William Pope, F.R.S., of the Chemical Laboratory of Cambridge University, stated that he wished more public men would follow the example set by the author, that is, try to show the great work of English chemists past and present and those in other branches of science, also to help to create an educated public opinion for British science and technology. He added that if those representing science and technology would put forward their point of view with the same insistence that the classical folk seem able to bring to bear, much more rapid progress would be made.

Sir William Pope agrees that the part played by Germany in chemistry has been made the most of, and that we need not fear comparison in this or other branches, including metallurgy and engineering. As an example of German methods, Sir William considers we are lacking in this country in the production of scientific publications of the compendium type. Germany has recently published a complete compendium on organic chemistry, the fourth edition in fifteen volumes of Beilstein's "Organische Chemie," beautifully printed and got up; but nearly all the references to English original work are to German translations thereof, and not to the English journals in which the work appeared. With the references made in this way the cursory reader is apt to assume that as German publications are referred to, the work has been carried out by Germans, whereas such remarks are only a translation of the original, representing British work. This is the reason, as Sir William said, why

"Chemistry is regarded as a German science!" Similarly, the German Chemical Society has just published an excellent and exhaustive analysis of the work done in recent years on the determination of atomic weights; scarcely a German name is quoted, because all the work that counts in this subject has been done of late in England, America and Switzerland. But the effect of this most excellent review is to represent a critical table of atomic weights as a German achievement.

Finally, Sir William Pope drew attention to the most excellent book on "Chimie et Guerre" by the great French Chemist, Moureu, who shows in a very able and clear manner how greatly exaggerated have been the claims put forward on behalf of the German chemist.

Before dismissing this subject the author would like to quote from a most interesting letter received from one of our leading chemists, Sir William Tilden, F.R.S. He says:

> "And this is the conclusion I come to, that it is almost impossible to estimate the relative positions of the nations by mere enumeration of names, as they are of such very different importance. Of course the Germans have laid claim to more than their due. At the same time no other people have any name to compare with the names of Baeyer and Emil Fischer. It strikes me that a safer comparison might be made by reference to the publications in each country. I think the Journal of the Chemical Society has been for some years a magnificent record of work done, being higher in quality than the Berichte and the American Journals. On the whole we have no reason to be other than proud of our work."

This, it must be admitted, is a fair and reasonable statement, showing that Great Britain is not merely holding its own but is well in advance.

Chemical Training and the Future.—Of the facilities for education and research in science generally more is said elsewhere in this book, but it is desirable here to refer, if only briefly, to certain matters which relate essentially to the maintenance of our national eminence in chemical research and to the application of our discoveries to industrial processes.

The author's own training as a chemist was under Mr. William Baker, then Professor of Chemistry at the Collegiate School, Sheffield; his son, Mr. C. K. Baker, still practises in Sheffield. Later, the author received further instruction from a chemist of considerable prominence, the late Mr. A. H. Allen, of Surrey Street, Sheffield, who was an original Fellow of the Institute of Chemistry, and Member of Council in 1877. Mr. Allen studied Chemistry under Hofmann and Percy at the

Royal School of Mines, before becoming assistant for a short time to Dr. Hassall. He was also Founder and President of the Society of Public Analysts.

Mr. William Baker used to give us most delightful weekly lectures each Saturday morning at nine o'clock at the Collegiate School, then under the able guidance of the Rev. C .B. Atkinson, M.A., who afterwards became a prominent coach at Cambridge. So greatly did many of us appreciate and benefit from these lectures with the demonstrations which accompanied them, that it ought to be possible for citizens of all classes of the Empire to hear such lectures on chemistry and physics, also to see demonstrations performed. The wonders of Nature's countless secrets gradually being unravelled by man are brought home to the mind by experimental demonstration in such a way as to encourage and stimulate thought. To witness such demonstrations and hear them explained is of great benefit, even to those whose ordinary interests and activities lie outside scientific channels.

For those who are studying science with a view to devoting their lives to its service, much more is required and, fortunately, is available.

In March, 1917, there was presented to the Faraday Society a symposium on the Training and Work of the Chemical Engineer. Several valuable papers were read, which deserved more attention than they received at the time. One was "The Training and Work of the Chemical Engineer," by the late Sir George Beilby, F.R.S.; another "The Training of the Chemical Student for work in the Factory," by Professor F. G. Donnan, F.R.S.

In his opening remarks as President on the occasion mentioned, the author pointed out the necessity for this country paying every possible attention to chemistry, and the importance of giving to the rising generation, of all ranks and classes, full facilities for the best possible training. The more urgent problems presented by the war doubtless affected the amount of attention which it was then possible to give to the improvement of chemical training, but the question was really one of national importance, and would be even more so in the event of another war. For that reason, and because of the increasing importance of the chemist in industrial work, this question ought again to be made the subject of debate.

There are wonderful facilities to-day for study and research

in every branch of science, and, considering the fields of metallurgy and chemistry alone, what would not early workers such as Dr. Priestley, F.R.S. (1733–1804)—and even the famous metallurgical chemist, Dr. Percy, F.R.S. (1817–1889)—have given to possess the opportunities offered to students in the well organised and well equipped laboratories of to-day? Nevertheless, these facilities and opportunities will not and cannot in themselves assure success. The lives and works of British chemists, living and past, encourage us to believe that in the future, as hitherto, we shall not be found wanting in regard to discoveries of fundamental importance; but there is perhaps a danger that the history of the aniline dye industry may be repeated, so that others reap where we have sown. This is a possibility which we must keep ever before us if we are to maintain our industrial status for, year by year, industry becomes more and more dependent upon applied science. Additional—and often prolonged—effort is required to maintain in the field of applied science a lead which is secured in that of pure science.

In his valuable Presidential Address to Section B (Chemistry) of the British Association at Toronto in August, 1924, Sir Robert Robertson, F.R.S., gave an interesting and helpful review of the development of chemistry in the modern state. Speaking of the general development of chemistry in this country he points out:

> "The war brought home the danger that, although the record of Great Britain as regards discovery in pure science was unrivalled, its systematic application before the war had been too often left to other countries, with the result of lamentable shortages during the war and the risk of many industries being ineffective in peace. Encouragement is now being given by the Government to workers in the academic field to follow out their ideas whithersoever they may lead them in accordance with the truth that 'research in applied science might lead to reforms, but research in pure science leads to revolutions' (in ideas)."

He also points out that it is important to be able to record an advance in securing an interchange of information among Government Departments, and between their work and that of the Universities, a matter which before the war was unsatisfactory, as it was mainly personal and sporadic. It is also a hopeful sign that, although the knowledge and apprecia-tion of the methods and capabilities of science are still generally wanting, there have been signs of late years that these matters

are coming to engage the attention of those who guide the policy of the State.

Technical Education for Artisans.—Though education of University rank—whether acquired directly or indirectly—is almost essential to those who would teach others or engage in research work, the needs of a large section of the community are best met by technical education which, though not inferior to University training, is directed in a somewhat different channel.

In considering the question of modern technical education it is particularly interesting to note how the attitude has changed during the last fifty years, and for the better. In Dr. Percy's Presidential Address to the Iron and Steel Institute, in 1885, considerable space was given to the consideration of this subject. Whilst he was naturally desirous to increase knowledge, some of us will not altogether agree with his attitude towards the technical education of artisans. In one section of his Address, Dr. Percy said :

> "It is, I think, to be regretted that not a few of the professed friends of technical education should have indiscreetly attempted to imbue all our artisans with the notion that the one thing which at present they urgently need is technical education, and that it will be certain to benefit them all alike. Now they will naturally be inclined to interpret the word benefit as meaning pecuniary advantage, or, in other words, an increase in wages. Believing as I do that this notion is incorrect and may be mischievous inasmuch as it is calculated to inspire a large class of our artisans with hopes which will never be realised, I venture to submit it to my hearers for their consideration. What is here meant by technical education is special instruction adapted to special artificers in addition to what they can acquire in the ordinary practice of their respective arts. Of the advantages of such instruction to many of our artificers, there cannot, I presume, be two opinions. But, on the other hand—and this is the point to which I desire to direct the particular attention of my hearers—I contend that there is a large number of artisans who will not be rendered more competent by instruction of that kind. In support of this contention let me adduce file-cutters by way of example, and others, whose sole industrial work is the performance of one and the same mechanical operation. Nothing in the way of manipulation is more calculated to excite surprise and admiration than the marvellous skill which a file-cutter displays in the practice of his art. This is, indeed, an illustration of technical education in the truest sense.
>
> "It would, I think, puzzle some of those gentlemen who talk so glibly and profusely about technical education to suggest an improvement in that of the file-cutter. Let him be saturated with knowledge of all the mysteries of iron and steel, and he certainly would not in consequence become a more skilful artificer, any more than would a sculptor by being informed that the marble on

which he operates is composed of carbonic acid and lime. Nevertheless, if our file-cutters and others desire special scientific instruction in iron and steel craft, no one can reasonably object to their having it."

Dr. Percy then referred to the important work of the late Sir Bernhard Samuelson, to whom he considered was due the credit of having been the first to succeed in convincing the House of Commons of the national importance of technical education in its widest sense, and to induce it, in 1868, to grant a select committee to inquire into the provisions for giving instruction in Theoretical and Applied Science to the industrial classes. He said:

> "If all the advocates of technical education had been as enlightened on the subject as Sir Bernhard, had acted as judiciously and disinterestedly, I should have been silent upon it. In order to guard against the possible misinterpretation of what I have said on that subject, I may be permitted to state that all the best years of my life have been spent in trying to aid the diffusion of special scientific knowledge in that branch of the industrial arts with which early in life I became fascinated, to which I have ever since devoted myself, and in which I feel as keen an interest as ever."

With the latter portion of this we can all agree, but as regards the earlier portion not entirely. Surely any artisan must be improved by acquiring increased knowledge.

Let us for a moment contrast the views of the present Labour Party. In a pamphlet entitled "The Education and Training of Teachers," recently published by the Trades Union Congress and the Labour Party, it is stated that at the very outset of the democratic movement there were various people who insisted that a much more comprehensive system of education must accompany the change in the method of government; that an uneducated democracy would be something like an anarchy. They did not use the word "education" in its narrower sense, but the theory that lay behind was that to govern anything, even himself, a man must have had a certain training; that it was a suicidal policy to put the government of the country into the hands of men who were uneducated—untrained, unacquainted with the knowledge and aspirations of the human race. They were not listened to, and the democratic experiment went on—not exactly a complete success. Presently the labouring classes themselves began to realise that to use the power put into their hands they needed this training. A certain and increasing measure of education has been given, and although there are few people who would be ready to assert that it is

enough, it is imperative that what has been given should be as efficient as possible.

With these two sets of views before us, it is possible and interesting to be able to make a comparison between 1870 and 1923, naturally much to the benefit of the later period, showing the great advance made by the workers in the desire to obtain more and better educational facilities.

Sheffield Trades Technical Societies.—Whilst in a general way Dr. Percy may have been correct in his remarks, there was hardly recognised sufficiently the great importance of trying to teach the workmen true and correct principles of the trades in which they were engaged. Surely this would make them far more valuable, not only to themselves but to the community at large. In this respect attention may be called to the valuable work being done by the author's friend, Professor W. Ripper, C.H., D.Eng., D.Sc., J.P., the Dean of the Faculty of Engineering in the Sheffield University and the Founder of the Sheffield Trades Technical Societies. These Societies cover the following six Sheffield industries: Cutlery, File, Silver, Edge-Tool and Saw, Foundry, and Rolling, Tilting and Forging. It will be noted that in the designations given is included one of the very trades referred to by Dr. Percy, that is file cutting.

Professor Ripper's object was that this movement might form, as it has done, a most useful connecting link between the University on the one hand and the various industries on the other.

The Societies are constituted on democratic lines, electing annually their own officers and council, and receiving from the Department of Applied Science assistance in the organisation of the movement. Each trade is thus responsible for the lectures, discussions, and research work that is undertaken for that trade, and, as all sections of the trade are represented on the Councils, there is in each case a governing body of practical and experienced leaders who are directing the attention of the trade to the various problems and issues which the lectures are planned to solve.

The meetings are held at the University, so that at least each month the various Societies are brought into direct contact with the various activities of the University including, of course, the Applied Science Department, and can avail themselves of the latest scientific and technical knowledge, should they desire to do so, on any particular problem.

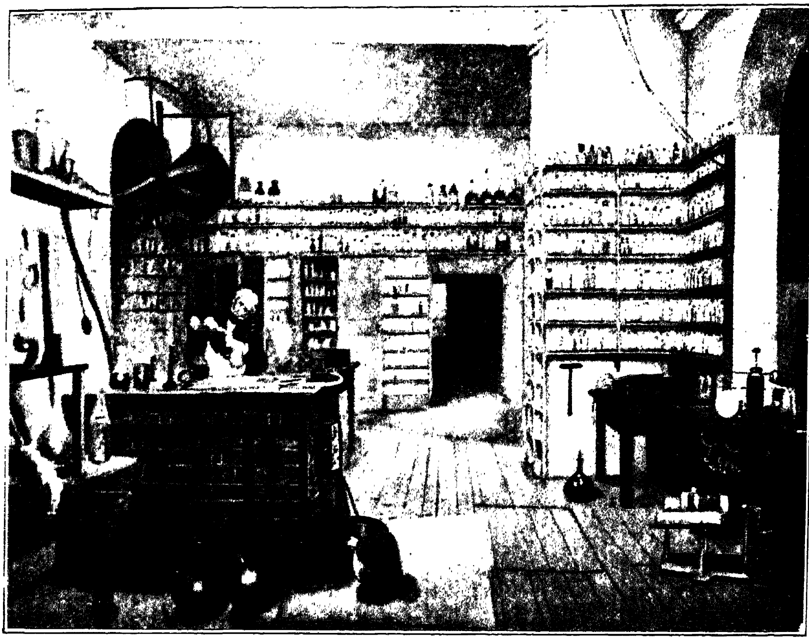
This movement has proved most excellent with regard to providing courses of lectures and promoting the reading and discussion of papers on subjects connected with the respective trades, with special reference to the needs of that large body of workers in each trade who are neither students of technical institutions nor members of scientific societies.

The lectures are given in a language which can be readily understood by the workmen, who are gradually becoming accustomed to the more scientific point of view with regard to the problems which have to be met in modern industry.

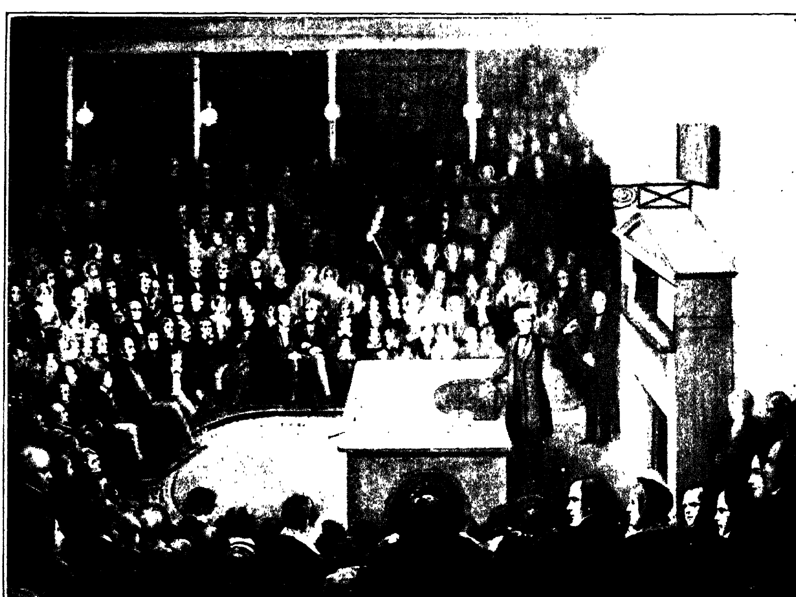
An incidental advantage is that the knowledge gained enables the workmen to follow, at least to some extent, the lectures of the more advanced Scientific Societies with profit and understanding.

The most important result, however, is the bringing of all sections of the trades together to consider the best means of solving the many problems which confront them. It seems certain that this movement will spread still further with the best possible results to the trades and to those engaged in them, and the University feels that in encouraging this movement and in opening out these new opportunities to the large class of workers, who have hitherto been outside such influence, a useful piece of work is being done that may be far-reaching in its effects both economically and socially.

In his younger days the author derived great benefit from lectures accompanied by experimental demonstrations. Similar opportunities ought, undoubtedly, to be made available to citizens of every class. This rational and most interesting way of imparting a knowledge of scientific subjects is exemplified by the Lectures of the Royal Institution, Albemarle Street, London. In this historic building, founded by Rumford in 1799, some of our greatest men have for very little stipend given their life's work to scientific education, and the permanent lecturers have been not only of national but international importance. The men referred to are Thomas Young, Humphry Davy, Faraday, Brande, Tyndall, Frankland, Odling, John Hall Gladstone, Crookes, Rayleigh, Thomson, down to Dewar himself, and now the mantle has fallen upon one of Britain's great men of Science, Sir William Bragg, F.R.S., who has won great distinctions, including the Nobel Prize. To give some idea of the work carried on at the Royal Institution, it may be mentioned that last session about eighty separate lectures were



The Royal Institution Laboratory, showing Faraday at work.



Faraday Lecturing before H.R.H. the Prince Consort, December 27th, 1855.

to house, catalogue and complete the Latimer Clark collection. There are two volumes containing 979 pages in all, with 5,966 entries, including the titles of over 1,900 separate books, and in many cases with epitomes of the contents, as well as pamphlets and sets of 114 different periodicals. In addition there is an interesting list of references to an imaginary magnetic telegraph known as the Sympathetic Telegraph, which occasionally figures in early electrical literature.

There are many reproductions from the books themselves, either of a title page, a significant page of text, or a page of illustrations.

The entries are in chronological order, and the date of the earliest entry is 1473. The latest, evidently representing an addition to the original collection is 1906. The dates, however, in many cases refer to a particular edition of a much older book. Thus there are in this wonderful collection, editions of Lucretius, Pliny, Claudian, Friar Bacon, Albertus Magnus, Agricola and Sacro Bosco, the edition of whose book "De Sphera Mundi" published in 1478, was the text expounded by Galileo at Padua. It is mentioned that Joannes de Sacro Bosco (John of Holywood) was educated at Oxford, so that it is quite possible this renowned University may well claim to have exerted some influence upon Galileo, and the spirit of experimental inquiry which he made manifest.

An early link with the Royal Society is indicated by the book "Experiments and Notes, about the Mechanical Origine or Production of Electricity," by the Honourable Robert Boyle, Fellow of the Royal Society, London; printed by E. Flesher, for R. Davis, Bookseller, in Oxford, 1675.

There are also many facsimile copies of letters of scientific men, including for example some by Faraday.

It will, therefore, be understood that the collection contains many books and pamphlets not to be found elsewhere, and includes some of the very earliest examples of printing.

The title entries of the catalogue are accompanied by descriptive and critical notes. These notes, and an admirable introduction, were prepared by Brother Potamian, D.Sc., Lond., Professor of Physics at the Manhattan College, and in themselves are an addition to the literature of electricity and magnetism of very high merit.

The preparation of the notes involving an examination of practically every work in the collection, occupied seven years,

and Brother Potamian has rendered specially valuable service in pointing out the nature of the contributions of many workers during the period when Latin was the common language of learned men.

Owing to the historical character of the collection, the chronological arrangement of the Catalogue is very convenient, and there is also an index to authors covering some twenty-nine pages. In this way any part of this vast accumulation of information is rendered readily and almost immediately accessible.

In reading the Introduction one is bound to be impressed with the numerous anticipations of modern knowledge on the part of some of the old writers. Many of these were only in imagination, but others seem to have been realised experimentally even in those old days. The aphorism "nil sub sole novi" is well illustrated.

The development of the idea of a region of force surrounding a magnet is traceable in the collection from some experiments recorded by Lucretius 99–55 B.C., down to the clear recognition by Norman in 1581, of the "Vertue in sphericall forme extending round about the Stone (lodestone) . . ."

Baptista Porta, 1538–1615, describes the manner in which two friends are supposed to converse instantaneously with each other over continents and oceans by means of a pair of compass needles, having the letters of the alphabet written on a dial-plate around them.

Among the title entries is to be found mention of a book on electricity by John Wesley, the founder of Methodism, and of another by Oliver Goldsmith, the poet and naturalist.

There is an interesting reference to Faraday in the Introduction by Brother Potamian in which he says, "In July, 1857, Mr. Clark invited Faraday to attend a séance of a spiritualistic character, which elicited from the Professor such condemnatory remarks as the following: 'But how is it that the believers in these things make such a shouting-out for scientific men? Why not become scientific themselves and prove their own so-called facts as scientific men prove theirs?'"

It will be evident that through the labours of Brother Potamian it is possible in this catalogue to trace in considerable detail the evolution of the sciences of electricity and magnetism. In fact, much of the early scientific work, including metallurgical, is to be found in this wonderful selection.

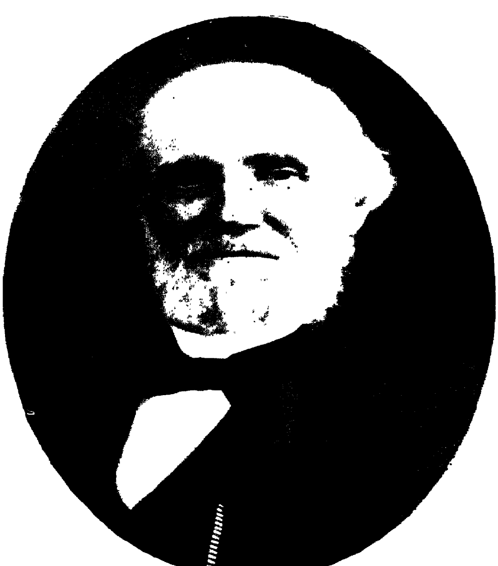
Some of the author's earliest studies of metallurgy were made from Percy's excellent works, including those relating to ferrous and non-ferrous metallurgy, fuel, and other kindred subjects. Percy, whose portrait is shown on Plate LXIII was a man with astonishing energy and great genius. Several of his books are classic and, even to-day, useful for reference. It is not too much to say the study of those books contributed very appreciably towards the author's taking up the investigation of alloys of iron with other elements. The fascinating descriptions of the thousand and one experiments carried out by Percy, could not fail to arouse interest and eventually bring to the mind of anyone carefully studying them the great possibilities of steel alloys. As Faraday's records show, his master-mind was also attracted in this same direction. The early studies of these two great men have happily matured to the enormous benefit of the world at large, and it is a matter of no little satisfaction and encouragement to have worked in this same direction.

The author was also influenced to a remarkable extent by two of Pepper's Books, one "The Play-book of Metals," and the other "Cyclopædic Science Simplified," published in 1869. The latter book has been rewritten by Dr. Mastin, and some years ago the author presented a number of copies to the Education Committee of the various Schools of Sheffield, all of which were distributed apparently with useful effect. The Senior Inspector of Schools, Mr. T. W. Quine, wrote from the Sheffield Education Office saying that the distribution had been found useful in supplying scientific information beyond that of the ordinary school book. The books presented had been used for scholars in Standard VI and VII, and practically all the Head Teachers stated that more copies would be genuinely appreciated.

Another valuable book, now nearly 50 years old, but still as useful as ever, is *The Art of Scientific Discovery* by Dr. George Gore, F.R.S., whose portrait is shown on Plate LXIII.

In the course of a long career as teacher in Birmingham, Gore conducted many scientific researches and did much laboratory work, specially in the field of electro-deposition, but if he had done nothing beyond writing *The Art of Scientific Discovery,* he would have established his reputation by that alone. What Roget's *Thesaurus* is to the literary man, Gore's *Art of Scientific Discovery* might be to the students and research workers of

Dr. JOHN PERCY, F.R.S.
1817-1889



Dr. JOHN GORE, F.R.S.
1826-1908

to-day were it easily available, but unfortunately the book has long been out of print. It well deserves to be reissued, for the precepts and guidance which it contains are as applicable to modern research, whether purely scientific or technical, as they were nearly half a century ago.

In Appendix V there is given a full extract of the views he expressed in 1878, on the general conditions and methods of research in physics and chemistry. The guidance there set forth should make the book be read by all younger men studying and engaged in research questions.

It was Gore who, as mentioned in Chapter IX, by observing a curious interruption in the steady contraction of iron when it is cooled, initiated the investigations which were subsequently made by others into the internal changes produced in steel and iron by heat; thus resulted the knowledge underlying the benefits derived from the present-day practice of heat treatment, without which the full and best qualities of steel are not developed. Other metals, with the exception of nickel and cobalt, show very little change under heating and cooling; and the changes which do occur in these two metals are in no way so pronounced as in iron.

Gore's wonderful powers of observation, without which he could not have written so excellent a guide for others, were applied to many valuable series of experiments, and he contrived that his services to the great cause of Research should extend beyond his own lifetime for, by his will, his residuary estate was divided equally between the Royal Society and the Royal Institution for the purpose of assisting original scientific discovery. The share of the Royal Society, amounting to nearly £2,500, has been invested as the Gore Fund.

Though stress has been laid upon the advantages to be derived from a study of certain earlier works, it is not, of course, suggested that modern works should be neglected on their account. On the contrary, in these days of rapid advance, it is very necessary to read as widely as possible and, as it is impossible to read all the literature that pours from the world's printing presses, the only practicable course is to follow closely the writings of the acknowledged leaders in one's own and kindred branches of science and, for the rest, to read technical periodicals and abstracts so that important contributions, from whatever source, may not be overlooked. Over-specialisation is a danger to be avoided, and the discussions

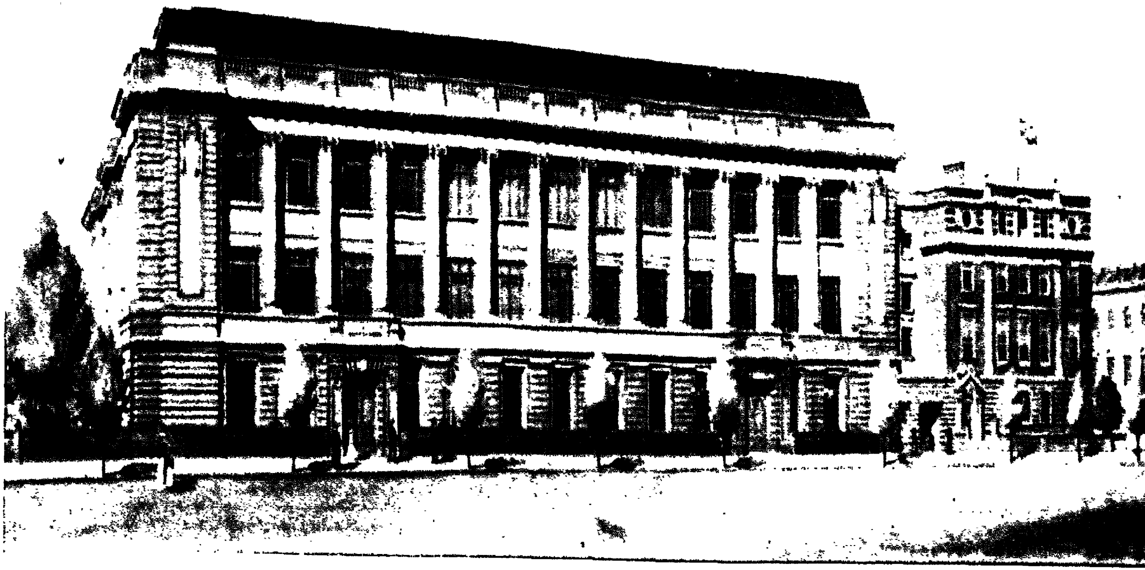
on papers read before scientific societies of all kinds are invaluable in giving to members a breadth of outlook and powers of criticism otherwise unattainable.

Another difficulty arising from the rapidity of modern progress is that of keeping scientific and technical books up to date. It is obviously important that a treatise which professes to deal with modern theory and practice should not be behind the times and, in this connection, reference may be made to a recently published statement concerning the Illinois Committee on Public Speaking. This Committee has made a thorough survey of the textbooks on economics, sociology and civics which are used in the public schools of Illinois, for the purpose of finding out just how the subject of public utilities is treated, locating obsolete information on the industry such books may contain, and assisting the authors thereof in obtaining authentic, up-to-date statistics and data on the entire industry. This principle might well be applied by appropriate Committees to textbooks in general. Valuable service would thus be rendered to the community, and all authors and publishers of high standing would surely welcome assistance in raising the standard of their works.

The Science Museum.—One of the finest educational facilities at our disposal to-day is the Science Museum at South Kensington. This contains a unique collection of exhibits which ought specially to be brought before all the younger men, of whatever class, of our country. By preserving appliances which hold honoured places in the progress of science or in the history of invention, and are associated with the names of the great men responsible for these advances, the Museum is at once a physical and living history of our past, and a potent source of intellectual inspiration. From the achievements—and even from the failures—of the past, valuable lessons for the present can often be gleaned and, over and above its historic interest, the Museum is a permanent exhibition of current practice in the various departments of science and technology.

The Museum was commenced in 1857, and has been growing steadily ever since. From the first it has been difficult to accommodate all the exhibits available, and in these days of rapid advance the problem of space is not likely to become easier, but it is one which must be solved if the Museum is to maintain and increase its national value. The Museum is at present under the able Directorship of Colonel H. G. Lyons,

PLATE LXIV



EASTERN FRONT OF THE SCIENCE MUSEUM AS IT WILL APPEAR IN 1927.

F.R.S., to whom the author is indebted for the photograph reproduced in Plate LXIV showing the Eastern front of the Museum as it will appear in about two years' time, i.e. in 1927. The Director is aided by an Advisory Council which includes, amongst others: Sir Hugh Bell, Bt. (Chairman), Sir Richard Glazebrook, Sir Thomas Holland, and the Hon. Sir Charles Parsons. The author was himself a member of this Council for four years, and was able to see the inner and most satisfactory working of this organisation.

Science and the Nation.—From the preceding pages which outline, though inadequately, the educational facilities now at the disposal of students, it is evident that these facilities are capable of meeting every reasonable requirement. The extent to which they are utilised depends partly upon ourselves as a nation, but mainly upon ourselves as individuals.

From the national standpoint the composition and attitude of our Government with regard to science leaves much to be desired. In saying this, reference is made to the Government as an institution and to no particular Minister or Ministers. Also, it is not overlooked that there have been improvements during recent years in such directions, for example, as the formation of the Department of Scientific and Industrial Research. Nevertheless, as the author pointed out in a contribution to the conference on "The Neglect of Science" held in London, on May 3rd, 1916, it is a remarkable fact that during the last hundred years there has apparently only been one scientific man holding an official position in the Government of the day. This surely explains why science has not had—and even now is not obtaining—due influence in the councils and policies of the nation.

The importance of science itself, and of its proper, organised study, demands a Minister of Science. Personally the author is convinced that extraordinary advantages would spring from such an innovation. Our pure scientists still hold their own in the world, and it cannot be said that our workmen or artisans are at fault. It is the still greater application of science to industry that we must foster and encourage, and a most important step in this direction would be made by giving men of science responsible posts in the Government.

Without referring to any particular individual, it is curious to reflect that, as *Nature* said some time ago, "apparently a Minister of Health need not know anything about science in

order to control the manifold activities of a department mainly concerned with scientific problems." Also, it is disconcerting to find that several different Government posts may be occupied by the same Minister during the course of a single year! In calling attention to such anomalies there is not the slightest intention of criticising individual Ministers. The system, however, does seem to be wrong, and, whatever may be done in other Ministries, if we are to have a Minister of Science he must be a scientific man, otherwise our last state will be worse than our first.

In the commercial field the same principles apply. Though it can never be responsible for all the technical details of a business, every Board of Directors ought surely to possess sufficient technical knowledge and ability to consider intelligently, and endorse or veto, the proposals of its technical experts. Any body—whether public or private—which wields power without knowledge may be likened to a motor car out of control, and sooner or later disaster is inevitable. If we are to meet the competition of other nations, it is essential to give science its rightful place in Government and industry.

We must not rest satisfied with matters as they are, and in this connection some words may be quoted from one of our most eminent chemists, Sir William J. Pope, F.R.S., who did so much for the country during the War. He strongly recommends consideration of the formation of an Advisory Science Committee in connection with the Government or the Board of Trade. It is well known that the Advisory Committee of the Department of Scientific and Industrial Research does not meet this want, because it has no power nor can it introduce points with regard to the importance of science to every man, woman and child in the kingdom.

In the Civil Service examinations every possible encouragement is given to classics, but training in science is left quite in the background. The marks obtainable for science are only about 10% of the whole. In an important Government establishment in this country devoted to educational work, about 90% of the principal officials are of classical education and about 5% of scientific training. It is therefore small wonder that the teaching of science has been considered as of almost secondary importance.

It is also regrettable to think, as recently stated by a well-known educational expert, that there are in this country about

three million young people, 80% of whom, between the ages of fourteen and eighteen, attend neither day nor evening school. In some cases their education comes to a dead stop at the age of twelve.

One of the leading scientists of the day, Sir J. J. Thomson, Past-President of the Royal Society, has made the following important statement:

> "The need for a greater appreciation of the value of science has been brought into such prominence by the war that most of those who have advocated the claims of science in Education have not unnaturally laid the greatest stress on the importance of science to the welfare, the power, and even the safety of the nation. The supporters of literary studies have, on the other hand, dwelt mainly on the fact that literature broadens a man's horizon, and gives him new interests and pleasures, that it teaches him how to live, if not how to make a living.
>
> "There is a tendency to regard science teaching with suspicion, as being intended to make the working man more valuable to his employer rather than to increase the brightness and interest of his own life.
>
> "I recognise—and I know no man of science who does not—the necessity of literary studies as a part of the education of every boy and girl, but I must protest against the idea that literature has a monopoly in the mental development of the individual. The study of science widens the horizon of his intellectual activities, and helps him to appreciate the beauty and mystery which surround him. It opens up avenues of constant appeal to his intellect, to his imagination, to his spirit of inquiry, to his love for truth. So far from being entirely utilitarian, it often lends romance and interest to things which, to those ignorant of science, make no appeal to the intellect or imagination, but are regarded by them from an exclusively utilitarian point of view. A knowledge of science brightens and widens the intellectual life, and is a constant stimulus to the intellect and imagination.
>
> "The question of the position of science in schools is of vital importance; I think we ought also to pay attention to the need for sustaining and stimulating in after-life the interest in science which we hope will have been aroused at school. We should encourage and develop efforts to bring to the notice of the public those results of science which are of general interest. I am not sure that we do all that is possible in this direction, and yet it seems our duty to the community to give it everything which can add interest to life and stimulate the intelligence; to do everything in our power to increase appreciation and interest in science among our citizens; without such appreciation a full utilisation of the resources of science and adequate encouragement for its development is impossible in a democratic country."

The Road to Knowledge.—The extent to which our educational facilities are utilised, and hence the degree to which, as a nation, we benefit therefrom, depends ultimately

upon individual application. The road to knowledge is necessarily long and hard. Sustained effort is demanded from each and every traveller who passes along it. The fruits of knowledge may be bought, but knowledge itself can be acquired only by work.

In a lecture entitled " What the Manufacturer expects of his Chemists," Mr. G. Lemmens, Managing Director of the Firm of Lipton, said: " There is only one royal road to knowledge, that is drudgery. An essential for any technical man is that he should be endowed with genius, that is with an infinite capacity for taking pains, and with intelligence enough to know that if he tries to cut corners or take short cuts, he will miss his way."

Drudgery does not sound pleasant or tempting, nevertheless Mr. Lemmens is correct. Faraday, when he started work at the Royal Institution and had to wash the glass-ware in the Laboratory, must have thought this to be drudgery, but from this small beginning he was able greatly to help the world's progress—an ambition for each one of us, than which there can be no higher, far above rank, position, or wealth.

Let us remember, too, the saying of one of the greatest scientists the world has yet produced, M. Louis Pasteur, who made discoveries of incalculable benefit to humanity. By one discovery alone, relating to the prevention of anthrax, it is estimated that he saved France a sum equal to the whole cost of the indemnity paid by that nation to Germany after the War of 1870. His views with regard to research work are expressed in the following conclusions, well worth remembering: " There is no greater charm for the investigator and worker than to make new discoveries, and his pleasure is heightened when he sees that they have a direct application to practical life."

Again Mr. Henry Ford states no mere truism when he says that " the only thing to do is to work—to recognise that prosperity and happiness can only be obtained through honest effort. Human ills flow largely from attempting to escape from this natural course. Work is our sanity, our self-respect and our salvation."

Success in the highest sense of the term, is to be won only by rigid adherence to the precept " Work hard," which is the true key to knowledge.

CHAPTER XIV

SCIENTIFIC SOCIETIES.

The Royal Society.—Oldest and foremost amongst the scientific societies of this country is the Royal Society, admission to which is by merit alone and constitutes one of the highest and most prized distinctions to which the scientific worker can aspire. Membership of the Society is restricted to no particular branches of knowledge. The aims of the Society, already discussed in Chapter XII, remain unaltered after more than 260 years of existence, and in the space here available it is not possible to deal with the present work of the Society and its many modern ramifications, the aid it gives to the Government in administering Research Grants, also the great scientific work it controls at the National Physical Laboratory—so ably conducted for many years by Sir Richard Glazebrook, F.R.S., to whom the Nation owes a debt of gratitude, and now by Sir Joseph Petavel, F.R.S. Those further interested will find valuable information in the following books: *The Royal Society, or Science in the State and in the Schools*, by Sir William Huggins, K.C.B., O.M. (1906); *The Record of the Royal Society* (1912); *The Signatures in the First Journal Book and the Charter Book of the Royal Society, being a facsimile of the Signatures of the Founders, Patrons, and Fellows of the Society from the year* 1660 *down to the present time* (1912); *Annals of the Royal Society Club*, by Sir Archibald Geikie (1917); *Annals of the Philosophical Club of the Royal Society*, by T. G. Bonney.

Professional Societies.—In a different, but no less useful, category are the many technical and professional Institutions and Societies open to any person whose work and interests lie in appropriate fields. To all the younger men who are preparing to adopt as their profession one or other of the branches of pure or applied science, the author specially urges the desirability of joining one of the great scientific or technical institutions at the earliest possible moment.

For the purposes of his Presidential Address to the Society of British Gas Industries in 1918, the author prepared the statement reproduced in Table XVII, showing the number of scientific and learned societies at work in Great Britain and Ireland. Though a few new societies have since been formed this statement is still substantially correct and the information which it presents concerning the distribution and classification of societies is distinctly interesting.

TABLE XVII.

SCIENTIFIC AND LEARNED SOCIETIES IN GREAT BRITAIN AND IRELAND.

	England.		Scotland.	Ireland.	Total.
	London.	Country.			
General Science	16	41	10	2	69
Mechanical Science and Architecture	30	28	7	4	69
Chemistry and Photography	10	2	—	1	13
Naval and Military Science ..	3	1	—	—	4
Economic Science and Statistics ..	12	14	3	2	31
Mathematical and Physical	14	3	2	—	19
Agriculture and Horticulture ..	3	3	2	1	9
Geography, Geology and Mineralogy..	12	7	3	1	23
Biology, including Microscopy and Anthropology	24	51	11	5	91
Medicine ..	32	18	9	1	60
Archaeology	18	37	3	5	63
Law	3	72	—	—	75
Literature and History ..	34	22	6	4	66
Psychology ..	9	—	—	—	9
	220	299			
Totals ..	519		56	26	601

A list of the principal engineering societies of the British Empire, together with the approximate membership of each, is presented in Table XVIII. As suggested later, it is to be hoped that the interests and influence of these societies will be furthered by a scheme for close and active federation.

TABLE XVIII.

PRINCIPAL ENGINEERING SOCIETIES OF THE BRITISH EMPIRE.

	Approximate Membership.
Institution of Civil Engineers	9,600
Mechanical Engineers	8,250
Naval Architects	2,900
Electrical Engineers	11,300
Mining Engineers	3,200
Mining and Metallurgy	2,500
Municipal and County Engineers	2,800
Marine Engineers	2,850
Automobile Engineers	1,900
Structural Engineers	1,600
Gas Engineers	1,000
Society of Engineers	650
Institution of Water Engineers	450
Iron and Steel Institute	2,250
Institute of Transport	2,000
Institution of Royal Engineers	1,280
Institution of Civil Engineers of Ireland ..	480
Institution of Engineers and Shipbuilders in Scotland	2,100
North-East Coast Institution of Engineers and Shipbuilders	1,600
Liverpool Engineering Society	680
South Wales Institution of Engineers	870
Engineering Institute of Canada	4,100
Institution of Engineers of Australia	2,100
Institution of Engineers of India	680
New Zealand Society of Engineers	330
South African Society of Civil Engineers ..	360
TOTAL	67,830

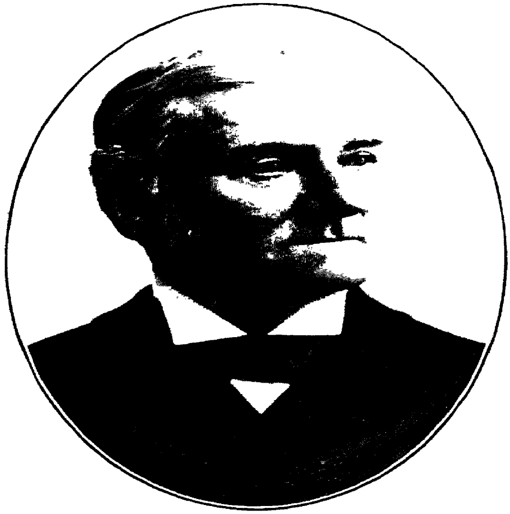
To attempt anything in the way of a complete account of all these scientific societies would go far beyond the scope of this book; but there is given, in the following pages, leading information, particularly concerning some of the Institutions and Societies with which the author has been associated during a period of many years. It has been his privilege to

serve as President of Sheffield Metallurgical Society, 1894–5; Iron and Steel Institute, 1905–7; Faraday Society, 1914–20; Society of British Gas Industries, 1917–18; British Commercial Gas Association, 1919–20; and he has been a Member of the Council of the Iron and Steel Institute for 35 years; of the Institution of Civil Engineers for 16 years; of the Institution of Mechanical Engineers for 17 years; of the Institution of Electrical Engineers for five years; and of a number of other institutions and societies for many years. By reason of these associations, and because of the many papers he has been privileged to read before the leading Institutions, the author has special pleasure in presenting the following review of the activities of these bodies.

The Institution of Civil Engineers.—This great Institution was founded on January 2nd, 1818, at a meeting held in the Kendal Coffee House, Fleet Street. The history of its origin and progress is related in a valuable paper read by Dr. J. H. T. Tudsbery, D.Sc., M.Inst.C.E., then Secretary of the Institution, on January 2nd, 1918, to commemorate the centenary of its foundation. From its earliest days the Institution has vigorously pursued its object of promoting and diffusing the knowledge necessary for the efficient practice of all branches of civil—as distinct from military—engineering, and it still maintains that catholicity notwithstanding the fact that other great institutions have been formed which concern themselves with single divisions of the vast field of engineering. To give some idea of the extent of this field, it may be mentioned that the Council of the Institution of Civil Engineers invite original communications on no less than 165 specified subjects, classified under the main headings: Railways; Roads; Waterways and Maritime Works; Machinery; Mining; Metallurgy; Shipbuilding; Waterworks; Sewerage and Gasworks; and Applications of Electricity. Most of these headings represent branches of engineering which support important Institutions of their own, yet all come within the scope of the Institution of Civil Engineers.

The meetings first held at the Kendal Coffee House were transferred to Gilham's Coffee House in 1819, and to a house in Buckingham Street, Adelphi, in 1820. On March 21st, 1820, Thomas Telford accepted an invitation to become the first President of the Institution, which then grew steadily in

SECRETARY OF THE INSTITUTION OF CIVIL ENGINEERS
1859-1896



James Forrest

FIRST PRESIDENT OF THE INSTITUTION OF CIVIL ENGINEERS
1820

Thos. Telford

importance and received a Royal Charter of Incorporation on June 3rd, 1828. A portrait of Telford is given on Plate LXV.

The first paper presented to the Institution was that by Joshua Field, on April 27th, 1819, the subject being Canal Locks. The conversations and discussions held at the Institution during its early years were not published or circulated by it, but, to a limited extent, abstracts appeared in the *Athenaeum*. The "Proceedings" as we know them to-day began with a volume of five parts referring to the period 1837–41. The form then adopted has remained practically unaltered to this day, and has been adopted as a model by almost every engineering society since formed.

The purpose of the Institution, as defined by its founders and expanded in the well-known words of Tredgold, has always been interpreted most liberally. In addition to the services rendered by Members who have prepared papers for presentation to the Institution, much valuable work has been done by Committees entrusted with experimental research and allied investigation of engineering problems. In addition, a reference library has been formed, containing all literature relating to the profession and deemed to be worthy of permanent retention. The Institution has actively been concerned with the education and training of engineers, particularly those who seek recognition by it, and the examinations which it holds periodically are universally admitted to be a high test of merit. The latest important stage of the Institution's development concerns the mutual relations of the members as professional men, and their relations with the public who employ them. The authority accorded to the Institution's views on education and training for engineers, and its action in recognising proper technical and professional attainments, is testified by the weight attached to membership of the Institution by many public bodies, including those overseas.

These various branches of the Institution's work and influence deserve to be studied in detail, for it is hardly too much to say that they embody the general policy and ideals of all the leading professional societies of the world.

Amongst the many illustrious names on the roll of the Institution there are Telford, Maudslay, Rennie, Rendel, George and Robert Stephenson, G. P. Bidder, Brunel, Penn, Whitworth, Hawkshaw, Fowler, Hawksley, Lord Armstrong,

Bazalgette, Greathead, Baker, Wolfe Barry, Preece, White, Kennedy, Unwin, and others. To deal individually with these leaders would amount to writing a history of engineering for the past century, and would require a large voume to itself.

It is impossible, however, to proceed without making special mention of the past and present Secretaries to whom the Institution owes so much. The author remembers with gratitude the kindness shown to him on many occasions by the late Mr. James Forrest, Secretary from 1860 to 1896, whose portrait is reproduced on Plate LXV. The assistance and encouragement which he offered when the author was preparing his first technical paper, on Manganese Steel, was particularly appreciated, and no doubt many others received equally valuable and opportune help from one whose name was a household word in his generation, and in whose remembrance the James Forrest Lecture has been founded. His successor, Dr. J. H. T. Tudsbery, who retired so recently as 1921, has also rendered sterling services to the Institution and to the profession; from him also the author has received kind assistance on innumerable occasions. In the present Secretary, Dr. H. H. Jeffcott, the Institution has an able successor to Forrest and Tudsbery, and one who is discharging the duties of his high office with the greatest credit.

The Institution of Mechanical Engineers.—The first meeting of the Institution of Mechanical Engineers was held at the Queen's Hotel, Birmingham, on January 27th, 1847, and George Stephenson was elected the first President. The headquarters of the Institution were removed to London in 1877.

Since its foundation, the aims of the Institution have been to promote the science and practice of mechanical engineering in all its branches, and to give an impulse to inventions likely to be useful to the community at large; also to enable its members to meet and correspond, thus facilitating the interchange of ideas, and furthering the interests of the engineering profession.

The past presidents of the Institution include those who have helped to make the mechanical arts famous not merely in Great Britain but throughout the world. After George Stephenson there came Robert Stephenson, Fairbairn, Ramsbottom, Whitworth, Penn, Napier, Siemens, Hawksley,

Bell, Anderson, White, Unwin, and others who are happily still with us.

Although a metallurgist rather than a mechanical engineer, the author would point out that the two sciences work hand in hand. Metallurgists claim to be ahead, because without their products there would be little or no mechanical engineering. It is the mechanical engineers who take the iron and steel products of the metallurgist and work them into more finished forms; it is they also who help to produce appliances by means of which these products can be manipulated and dealt with more rapidly, on a larger scale, and their quality improved and perfected.

The Institution in the past has always wisely encouraged the metallurgical side of mechanical engineering by its Special Committees devoted to metallurgical subjects. One of its latest Committees over which the able Past-President, Dr. W. Cawthorne Unwin, F.R.S., presides, is devoting its attention to the question of hardness. It is hoped the results will be of great benefit, not only to the mechanical engineer, but also to the metallurgist. The Alloys Research Committee, established in 1889, has in the past done most excellent work, with which are connected such names as Anderson, Roberts-Austen, Gowland, Arnold, Stead, Harbord, Unwin, Huntington, Wrightson, and others. The first Chairman of this Committee was Sir William Anderson; then followed Sir William White; and now Sir John Dewrance.

By its visits to France, Belgium, Switzerland, and the United States of America, as well as to all the principal engineering centres in this country, the Institution has rendered valuable service to its members and, indeed, to the whole cause of British Engineering. The local branches of the Institution, which now cover practically the whole of England and parts of Scotland and Wales, are very active. Advisory Committees have also been formed in India, Australia, New Zealand and South Africa; whilst Local Correspondents act for the Institution in Argentina and the Federated Malay States.

The high standard of qualification established as a condition of membership has reacted to the benefit of members, and the Institution has been consulted by various Government Departments with regard to technical training and other matters. The author would here add that the Institution owes much of its success to the untiring energy on its behalf

of its late Secretary, Mr. Worthington. The author has known him for many years, and has never seen him fall short in anything concerning the interests of the Institution. The present Secretary is General Magnus Mowat, C.B.E., who is an able man, and is giving the Institution great help.

The Institution of Electrical Engineers.—This Institution, which has now a membership larger than that of any other engineering society in the Empire, was founded on May 17th, 1871, as the Society of Telegraph Engineers, Mr. C. W. (later Sir William) Siemens being its first President. In its early days the Society was necessarily chiefly concerned with telegraphic matters but, as the applications of electricity and magnetism developed, the Society widened its scope and title. In 1880 it became the Society of Telegraph Engineers and Electricians, and in 1888 the Institution of Electrical Engineers. A Royal Charter of Incorporation was granted in 1921.

The objects of the Institution as set forth in its Charter may be summarized as follows:—To promote the general advancement of electrical science and engineering and their applications, and to facilitate the exchange of information and ideas on these subjects by means of meetings, exhibitions, publications, the establishment of libraries, and the giving of financial aid to inventors and experimenters.

The Institution has advanced *pari passu* with the developments of electrical knowledge, being ever in the van of discovery, invention, and application. It is not limited in its interests and activities to any one section of electrical engineering, but embraces them all, and demands the same high qualifications for admission to its membership, whatever the section to which the candidate may belong. By framing rules for electrical installations of various descriptions and by drafting model conditions for contracts, the Institution has rendered valuable assistance to the electrical industry and, indeed, to the public at large. Other phases of its manifold activities are its participation in the work of the British Engineering Standards Association and International Electrotechnical Commission, with a view to securing standardisation and international agreement; and the labours of its representatives in the British Electrical and Allied Industries Research Association which is investigating many problems of the highest importance.

The author was particularly impressed by the admirable Presidential Address of Dr. Alexander Russell, M.A., D.Sc., F.R.S., in 1923 and would like to take this opportunity of emphasizing the importance and value of the work which he is carrying on at Faraday House, of which he has been Principal since 1909. The characteristic feature of the training provided at Faraday House is the invaluable combination of theoretical and practical tuition which is effected by "sandwiching" the college courses with periods spent in the works of affiliated companies, the latter including some of the best known mechanical and electrical firms in the country and a number of railways and power stations. The assistance which Dr. Russell has rendered to his students is well recognised by them, and the benefits they have derived have been shared by the industries in which they are now working.

The library of the Institution of Electrical Engineers contains about 15,000 volumes and embraces several historical and special collections besides the current volumes which have been acquired as published during the period of the Institution's existence.

In addition to the general meetings at which papers are read and discussed, there are informal meetings for the less formal discussion of all subjects concerning the electrical profession and industry. The visits arranged by the Institution at home and abroad have been most beneficial. In all grades of the membership and in every branch of activity there is remarkable virility, and the extraordinary vigour of the Local Centres is most striking and has done much to extend and strengthen the influence of the Institution. The services of its present Secretary, Mr. P. F. Rowell, have extended over many years, including the period of its most remarkable growth, to which they have contributed in no small measure.

The Iron and Steel Institute.—During the past half century the Iron and Steel Institute has played a most important part in encouraging research and disseminating scientific and practical knowledge concerning ferrous metallurgy at home and abroad, irrespective of nationality. The author counts it a special honour to have been President of this great Institute and to have received from it the award of the Bessemer Gold Medal. The first President was the Duke of Devonshire, in 1869–71; and soon afterwards on the roll-call of its famous

Past-Presidents follow the names of Sir Henry Bessemer, Sir Lowthian Bell, Sir William Siemens, Dr. Percy, Sir Frederick Abel, and many others well known in metallurgy.

In addition may be mentioned some of the names of those who have received the Blue Ribbon of Metallurgy in the form of the award of the much-prized Bessemer Gold Medal, established in 1873. Sir Lowthian Bell was the first recipient, followed, amongst others, by Siemens, R. F. Mushet, Percy, Whitworth, John Fritz, Howe, Arnold, Osmond, Brinell, Pourcel, H. Le Chatelier, Pierre Martin. The latest recipients in 1923–24 were Professor Honda from Japan, and Professor A. Sauveur from the United States of America, whose names help to show the cosmopolitan nature of the Institute.

An important landmark in the history and career of the Institute was the wide and munificent foundation in 1901 by Mr. Andrew Carnegie of the Carnegie Research Scholarships, which have been of such inestimable value in encouraging metallurgical research. Here again the awards have been international.

There is, therefore, no organisation which has been more cosmopolitan or done greater work on international lines than this Institute, which has had such able guidance and faithful service from its Secretaries. The first Secretary was Mr. J. Jones, who was assisted by Mr. David Forbes, F.R.S., acting as Foreign Secretary. He was followed by Mr. Jeans, then by Mr. Brough, and to-day by the present Secretary, Mr. G. C. Lloyd.

In 1916 the Institute decided to accept candidates for election as Associates at a specially low rate of subscription. Persons eligible for this privilege are those who do not exceed 24 years of age and are students of metallurgy, taking courses at a University College or technical school; pupils who are apprentices of metallurgists or engineers, or in metallurgical or engineering works; or persons employed in some practical or scientific capacity in metallurgical or engineering works. The subscription is exceedingly moderate—only one guinea per annum and no entrance fees—a less sum than most of even the small engineering societies charge for membership. This Associateship enables individuals interested in metallurgy to obtain at once the whole benefits of the Institute with the exception of voting, that is, an Associate has the right to attend all meetings and receive all notices and publications.

The Institution of Naval Architects.—Since its foundation in 1860 the Institution of Naval Architects has laboured ceaselessly to promote the development of naval architecture, both on the scientific and on the practical side. That the Institution has been, and continues to be, of great value to the shipbuilding and shipowning interests of this country goes without saying. Its value in these respects has been much increased by the fact that the membership and activities of the Institution have, from the first, embraced shipbuilders, marine engineers, naval officers, shipowners, yachtsmen, and, in fact, all persons whose business or vocation renders them able to discuss with naval architects the qualities of a ship or her equipment. From the outset, however, great care has been taken in scrutinising the qualifications of candidates before admitting them to membership, and this, combined with the diversity and breadth of interests represented, has resulted in the Institution gaining the highest recognition throughout the world. It is, indeed, to a great extent international in character, and its foreign membership has resulted in the establishment of similar institutions in many other countries.

For a President, the first choice fell upon the Duke of Northumberland, ancestor of the present distinguished holder of that office; he was, however, obliged to decline the honour. Sir John Somerset Pakington (afterwards Lord Hampton) was thereupon unanimously elected, and he was the only President to occupy that post while serving as First Lord of the Admiralty. He guided the destinies of the Institution for twenty years, and was then followed by a distinguished line of Presidents, amongst whom may be mentioned Lord Ravensworth, Lord Brassey, the Earl of Hopetown (later Marquis of Linlithgow), the Marquis of Bristol, the Earl of Durham, and now the Duke of Northumberland. To these men and to the successive Secretaries, including the present Secretary, Mr. R. W. Dana, O.B.E., M.A., M.Inst.C.E., the Institution owes much of its growth and influence.

It is interesting to note that in addition to its work in every phase of naval architecture, the Institution has contributed materially to the development of airships. The naval constructor proved to be best equipped for the difficult problem of designing structures which, though differing superficially from sea vessels, yet depended upon the same basic principles for construction.

The Institution of Mining & Metallurgy.—The Institution of Mining and Metallurgy, whose President this year is Sir Thomas H. Holland, F.R.S., was founded in 1892, and Incorporated by Royal Charter in 1915. By it are represented metalliferous mining and the production of non-ferrous metals, with a membership of about 2,500, election being made upon a purely professional basis. This Institution works in the closest co-operation with the Institution of Mining Engineers, founded in 1889, Incorporated by Royal Charter in 1915, whose President this year is Dr. John Scott Haldane, F.R.S. This Body is a federation of seven principal Institutes, and represents coal-mining engineering. Its membership is about 3,500. Mr. Charles McDermid is Secretary of both Institutions, of the former since 1900 and of the latter since 1921; a debt of gratitude is owed to him for the many valuable services he has rendered to these two Institutions.

The Institute of Metals.—The Institute of Metals, which is one of international character, was founded in 1908, the President this year being Professor T. Turner, who was one of the Founders. The total membership exceeds 1,600 and is increasing rapidly.

Its main object is "to promote the science and practice of non-ferrous metallurgy in all its branches." That object has been faithfully carried out by means of meetings for the reading and discussion of Papers, by the initiation and conduct of researches upon the corrosion of non-ferrous metals, and by other means.

The first President was the late Sir William H. White, K.C.B., F.R.S., and his successors have been drawn by rota from the three main classes of membership—users and makers of non-ferrous metals, also academic members.

The Secretary, Mr. G. Shaw Scott, commenced his work at the initiation of the Society, and has continued ever since to guard its interests in a manner which calls for the utmost admiration.

The Royal Aeronautical Society.—This famous Society was founded on January 12th, 1866—long before the realisation of aviation as we understand the term to-day. Its first president was the Duke of Argyll, F.R.S., and the roll of its officers and members includes many famous names, amongst them Sir Charles Tilston Bright, Sir William Fairbairn, F.R.S., James

Nasmyth, Sir William Siemens, Sir William Crookes, Sir Hiram Maxim, Captain Scott, the Antarctic explorer, and many others.

The objects of the Society at its foundation were "To foster and develop the science of Aeronautics and to increase our knowledge of Aerology." The objects at the present day are to promote the science of Aeronautics by: (*a*) organising discussions and publishing papers; (*b*) encouraging research; (*c*) conferring a technical status on members of the aeronautical profession; (*d*) encouraging technical students; (*e*) providing an organisation to bring together those interested in aeronautics from scientific or patriotic motives. The importance of this work at the present day needs no words to emphasize it. It concerns our national security and commercial prosperity alike.

Whilst the non-technical membership is open to all, thus encouraging widespread support for the objects of the Society, technical membership is, very properly, reserved for those who have the necessary qualifications.

The Institution of Automobile Engineers.—In 1898 a meeting of cycle engineers was held in Birmingham to promote the formation of a Cycle Engineers' Association. At that time the policy was for every manufacturer to make components differing just sufficiently, from those of other machines, to compel the user to send to the maker for all replacements—even if only a nut. At the same time, the "shop secrets" of the cycle trade were guarded most jealously, to such an extent, in fact, that several firms forbade their technical officers joining the proposed institution. Nevertheless the Cycle Engineers' Institute was formed in 1899, and, as the development of the motor car proceeded, the scope of the Institute was widened and its title was changed to the Automobile and Cycle Engineers' Institute in 1904, and to the Institution of Automobile Engineers in 1907.

The objects of the Institution in its present form are best expressed by the words of the Memorandum of Association: "To promote the science and practice of engineering as applied to . . . every kind of mechanical locomotion on land, on or in water or in air; and to initiate and carry through any scheme or to organise any movement likely to be useful to the members of the Institution and to the community at large in relation thereto."

The activities connected with these objects are many

and various; chief among them may be mentioned the reading and discussion of papers on subjects of value to automobile engineers; the assisting of those who are in course of training as automobile engineers, by means of papers, works visits, etc.; the issuing of data sheets for the use of automobile designers; the establishment of an Appointments Bureau to assist members in finding positions, and manufacturers in obtaining the right man for the job; and many other things too numerous to mention.

The work and status of the Institution are worthy of the great British industry which it represents.

The Institution of Structural Engineers.—Founded in 1908 and incorporated in 1909 as The Concrete Institute, this important society changed its title to The Institution of Structural Engineers in 1922, and now includes within its scope the consideration of all problems relating to structures in concrete, steel, brickwork, masonry, timber and earthwork. That this widening of scope was a move in the right direction cannot be doubted. The Institution has already performed valuable work and is, no doubt, destined to render the highest services to the cause of structural engineering in general, regardless of the particular purposes of the structures.

Much information concerning the Institution of Structural Engineers, as well as a fascinating account of the evolution of engineering institutions in general, is to be found in the Presidential Address delivered by E. Fiander Etchells, A.M.Inst.C.E., Hon.A.R.I.B.A., to the Institution of Structural Engineers in 1923. This address constitutes a most valuable addition to engineering literature, and traces in a most instructive manner the evolution of modern professional institutions from the guilds of bygone ages.

Chemical Societies.—In view of the special importance of chemistry to the scientific advance and industrial progress of this country, it is satisfactory to be able to refer to the excellent work being done by the Chemical Society founded in 1841; the Institute of Chemistry, founded in 1877; and the Society of Chemical Industry, founded in 1881. All who can should qualify to become members of one or more of these important bodies, the conditions of entrance to which are such that admission is, as it ought to be, a proud privilege.

As an example of the useful work being done, it may be mentioned that a deputation from the Institute of Chemistry

recently waited upon the Patent Office to press upon the notice of the authorities the great desirability of removing the present cases of hardship in respect of certain discoveries in the chemical world, patent protection for which could not at present be obtained, but which, if it could be, might prove of great service to industry in general.

Faraday Society.—Another Society which is doing splendid work is the Faraday Society which was founded in 1903. Sir Joseph Swan was the first President, and later Presidents have been Lord Kelvin, Sir Wm. Perkin, Sir Oliver Lodge, James Swinburne, Sir R. T. Glazebrook, Professor A. W. Porter, Sir Robert Robertson, and Professor F. G. Donnan who is now in office. The author had the privilege of serving as President for several years, and found that the Society was dealing with subjects not taken up by other Societies.

The object of the Society, as originally defined, was to promote the study of electro-chemistry, electro-metallurgy, physical chemistry, metallography and kindred subjects. Of late years the term physical chemistry has been given a wide interpretation, and the Society has taken within its ambit the whole borderland between physics and chemistry, both in its scientific and technical aspects. It also concerns itself with industrial applications of physics not covered by existing societies. The Society aims in a special degree at co-ordination between theory and practice.

One of the features of the work of the Society has been the organisation of general discussions on scientific and technical subjects of current interest. Two or three of these discussions are held in the course of the year and the reports of them, which are published separately, are eagerly sought after by those who wish to acquaint themselves with the latest developments and opinions in the subjects under consideration. Its popular Secretary, Mr. F. S. Spiers, has done most excellent work in organising the work of this useful Society.

The Faraday Society is, of course, named in honour of Michael Faraday, from whose discoveries in electrical science the world is now benefiting to such an enormous extent. On several occasions the author has dealt with Faraday and his life work, pointing out *inter alia* that so great is the fame of Faraday in the electrical world, owing to the enormous developments which have arisen from his discovery of magneto-electric induction, that there is a tendency to overlook the

fact that he was also a brilliant chemist. Yet his work in the field of chemistry alone would have established his reputation.

In 1820 Faraday published his discovery of two new compounds—chlorine, carbon and iodine; carbon and hydrogen —and in 1821 he was working on alloys of steel. In 1826 he published fresh discoveries of new compounds of hydrogen and carbon, and he was the discoverer of benzol. Improvements in the manufacture of optical glass claimed his attention, and he elucidated the laws of electro-chemical decomposition, ranking in importance, says Tyndall, with the law of definite combining proportions in chemistry. Add to these achievements, his electrical discoveries—on which rests the whole fabric of modern electrical engineering—and his researches in pure physics, to say nothing of his Lectures and his consulting work, and we begin to realise what kind of man was Michael Faraday. He was probably the greatest experimental philosopher the world has ever seen—the son of a blacksmith, being himself apprenticed to a bookbinder, working at that trade until about 22 years of age. He was then entrusted with the duty of keeping clean the famous laboratory of which he ultimately became the still more famous head. Surely there is in the tale of his life inspiration and encouragement for us all, and those who have not already done so should certainly read at least one of the biographies of Faraday by Tyndall, Bence Jones, J. H. Gladstone, or S. P. Thompson. Quite recently there has been published a short and most interesting account of Faraday's career, written by W. L. Randell, Editor-in-Chief of the "Electrical Press," London.

Institute of Physics.—One of the most recently constituted scientific bodies in this country is the Institute of Physics, which was founded in 1920. The first President was Sir R. T. Glazebrook, and subsequent Presidents have been Sir J. J. Thomson and Sir Charles Parsons.

The object of this Institute is to secure the recognition of the professional status of the physicist and to urge the importance of physics in industry. To this end the Institute grants diplomas to Corporate Members indicative of a high standard of professional capacity in physics.

Corporate members are of two classes, Associates (A. Inst. P.) and Fellows (F. Inst. P.) depending upon academic qualifications and research or professional experience. The Institute also

registers students of physics, and it keeps a panel of consulting physicists and a register of physicists available for appointments.

Among the activities of the Institute have been the organisation of a series of Lectures on Physics in Industry, of which two volumes have been published, and the foundation of the monthly *Journal of Scientific Instruments* which is edited at the National Physical Laboratory and produced under the auspices of the Institute of Physics.

Closely associated with the Institute, and represented on its Board, are the societies concerned with physical science and its applications, namely, the Physical Society of London, the Faraday Society, the Optical Society, the Röntgen Society, and the Royal Microscopical Society. The Institute has before it the aim of providing a central building and library for physics.

There is no doubt that the Institute is meeting a long-felt want, and all those who are studying Physical Science should consider the many advantages which can be derived from membership.

Other Societies.—Besides the institutions mentioned on the preceding pages there is also the most important and useful work carried out by the Institute of Marine Engineers; the Institution of Locomotive Engineers; the Institution of Municipal and County Engineers; the Society of British Gas Industries; the Institution of Gas Engineers; the Institution of Illuminating Engineers; the Institution of Water Engineers; the Junior Institute of Engineers; the Institute of Transport; the Ceramic Society; the Society of Glass Technology, and others representing the developments of Applied Science. Reference should also be made to the most excellent work being carried out by the British Science Guild, aided as it is by the wise counsel and assistance of its Chairman, Sir Richard Gregory. Much might be said concerning each of these did space permit; each one of them is rendering excellent service to the interests which it represents and therefore is entitled to the full support and active co-operation of those eligible for membership.

Federation of Societies.—On the principle that unity is strength, and because of the manner in which the many branches of science overlap and are interdependent, there is every reason for welcoming a federation of engineering and scientific societies—first on a national basis, and later, let us hope, on an international basis.

The Engineering Joint Council in this country was formed by four founder Institutions, viz. the Institution of Civil

Engineers, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, and the Institute of Naval Architects. The founder Institutions, which are permanent Members, come under class "A" because no members are admitted to these Institutions without a qualifying examination or passing a certain scrutiny. Other representatives come on the Council under class "B," that is, Societies or Institutions which elect members without examination though with full qualifications otherwise. This class covers for example the Iron and Steel Institute, the Institution of Gas Engineers, and others.

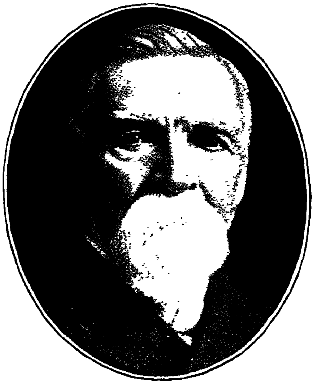
The scope and influence of the Joint Council is growing steadily, and it is to be hoped that it will result in the formation of an organisation corresponding to the United Engineering Society of the United States.

The United Engineering Society (U.S.A.).—This great Society comprises three departments, namely the Engineering Foundation Board, the Engineering Council, and the Engineering Societies Library Board.

The engineering future of America is in the hands of the Engineering Foundation Board. This Foundation, which in its Charter is described as "For the Furtherance of Research in Science and Engineering and for the Advancement in any other manner of the Profession of Engineering, and the good of mankind." was instituted on the 28th May, 1914, by one of America's leading engineers, Mr. Ambrose Swasey of Cleveland, Ohio, who gave the magnificent sum of $625,000 to help forward the objects of the Foundation. In addition, Mr. Swasey has many other claims to distinction. He is President of the Board of Trustees of the Dennison University, Ohio; Fellow of the Royal Astronomical Society; Member of the British Astronomical Society; and Member of the Institution of Mechanical Engineers (Great Britain). He was the builder of the great telescopes at Mount Hamilton (California), the Naval Observatory at Washington, the Yerkes Observatory at William Bay (Wisconsin), and the 72-in. reflecting telescope of the Dominion Astronomical Society at Victoria (B.C.).

The author recalls with great pleasure that Mr. Swasey was Chairman of the influential deputation sent over from America in 1921 to present to the author that much-prized distinction, the John Fritz Medal. The first award of this medal was to John Fritz himself, in honour of whose remarkable achievements

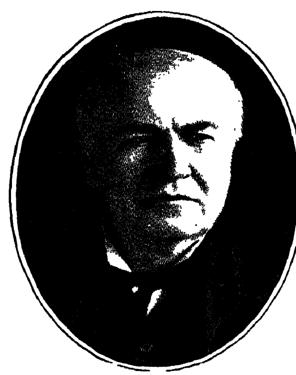
RECIPIENTS OF THE JOHN FRITZ GOLD MEDAL



JOHN FRITZ.

GEORGE WESTINGHOUSE.

A. GRAHAM BELL.



THOMAS A. EDISON.

LORD KELVIN.

ELIHU THOMSON.

RECIPIENTS OF THE JOHN FRITZ GOLD MEDAL.

George W. Goethals.

Orville Wright.

Henry M. Howe.

Sir William H. White.

Eugène Schneider.

G. Marconi.

[*Elliott and Fry.*

in engineering the John Fritz Medal Foundation was established by the four leading engineering societies of America. Amongst the subsequent American recipients of the Medal have been: George Westinghouse, Alexander Graham Bell, Thomas Edison, Charles Talbot Porter, Alfred Noble, Robert Hunt, John E. Sweet, H. M. Howe, J. W. Smith, General Goethals, and Orville Wright; whilst the English recipients have been Lord Kelvin, Sir William White, and the author of this book. Portraits of John Fritz, and some of those who have been awarded the John Fritz Medal are given on Plates LXVI and LXVII.

The Engineering Foundation is a federated association which now represents a grand total of probably more than 200,000 American Engineers, combining the four principal societies—the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers—as well as some forty smaller engineering societies. The Chairman of the Engineering Foundation is Mr. Charles F. Rand, whose portrait is given on Plate LXVIII.

The centre of these activities is the magnificent New York Building of the Engineering Societies, with all its wonderful conveniencies, at the opening of which the author was present on April 16th, 1907. This building was made possible in the first instance by the munificence of Mr. Andrew Carnegie, who gave towards its cost about one and a half million dollars. It is the one centre for conferences and meetings, the reading of papers, and other business, for some sixty thousand technical men in the United States.

There is no doubt that many advantages spring from this arrangement, such as better co-ordination of work done, the avoidance of overlapping of papers, or the presentation of papers to the wrong society, thus saving much valuable time and energy as well as preventing friction. Further, the secretaries of the different societies can freely exchange their views in a few minutes.

Another important advantage is that these societies have one Library common to all their members, made available solely for scientific and technical literature; the Library now contains about 170,000 different works and is under the charge of Mr. Alfred D. Flinn, Director of the Engineering Foundation.

For some time past, through the joint research instrumentality of the four principal member societies already mentioned,

the United Engineering Society has published semi-monthly "Research Narratives," which are circulated to its many thousands of members.

Each of these Narratives describes some important research development or invention which has helped on the World's progress. The total number of the Narratives is already over one hundred, and still they come; they undoubtedly act as an important stimulus to the minds of the younger men. The first volume entitled "Popular Research Narratives, being Outlines of Discovery, Invention and Research," contains about fifty of these "five-minute" stories, as they are termed, of research, invention or discovery directly from the "man who did it," pithily told in language for laymen, young and old. The index of subjects and comparisons is in itself a most valuable aid and guide to those interested in discoveries and inventions.

Is it too much to hope that our Engineering Council in this country will decide to encourage and establish something of the same order? They would receive very powerful support from the author's friend, Sir Richard Gregory, the Editor of "Nature," who has for so long given most able help in directing and encouraging educational matters.

The author is particularly pleased to find that several of the suggestions made in his Address of Thanks, given before the Institution of Civil Engineers on June 29th, 1921, on the occasion of the presentation of the John Fritz Medal, are being taken up very cordially in America. One of these recently under consideration was that there should be a federation, represented by a Council of Engineers, for all Anglo-Saxon speaking people. It seems quite possible that such an organisation would speak with greater force than the politicians of either country.

In the meantime there is an urgent need for a Central Engineering Council to represent, guard, and foster engineering interests of all kinds throughout our own Empire. Quite recently Mr. Edmund L. Hill, who has done so much to bring about the establishment of the Engineers' Club in London, said: "May it not be hoped that the time will come before long when those sections of Science represented by Engineering, Metallurgy, Chemistry, Architecture and other branches will build themselves a home worthy of their calling and of the Empire"—that is following the example of our American cousins in New York.

THE DEPUTATION OF AMERICAN ENGINEERS WHICH VISITED LONDON, JUNE 29th, 1921, TO CONFER THE JOHN FRITZ MEDAL.

Robert A. Cummings Charles T. Main Jesse Merrick Smith F. B. Jewett William Kelly
Ira N. Hollis Arthur S. Dwight Ambrose Swasey Charles F. Rand John R. Freeman

CHAPTER XV

METHODS AND FACILITIES FOR RESEARCH.

System and Correlation in Research.—Though inspiration, or even accident, may be responsible for some inventions and discoveries, it may safely be said that practically every instance of successful research is attributable to systematic work. From the author's own experience, extending over forty years, systematic correlation of research offers the best prospects of success and the best insurance against valuable discoveries being missed by incomplete exploration of the field.

In 1905, when the author was President of the Iron and Steel Institute, that body paid a visit to Sheffield, and on that occasion the late Dr. Wedding, of Berlin, the leading German metallurgist of his time, stated that "The research work carried on at the Hadfield Works was of a completeness which would serve as an example to every academy in Germany." Every kind of test is applied—chemical, mechanical and physical—and there is equipment for carrying out tensile, bending, endurance, impact, hardness, electrical conductivity, magnetic permeability, hysteresis and recalescence tests. In a single week as many as 12,000 pyrometic observations have been made.

An admirable example of systematic procedure in research is afforded by Gore's classification of types of research and methods by which discovery and invention may be attained. This classification is reproduced in Appendix V from that admirable book *The Art of Scientific Discovery*, to which reference has already been made. It shows clearly how many avenues must be explored before we can claim even moderately complete knowledge of a subject; also, how much might be sacrificed by failure to do so.

The truth and importance of these statements are demonstrated in a very striking manner by the discovery of manganese steel. Hundreds of thousands of tons of this

alloy have been made, mostly for use where no other material could be employed, or where the cost of keeping other material in repair would be prohibitive. This extensive utilisation is an index of the direct practical importance of the discovery of manganese steel, but in the author's opinion the discovery was of even greater importance in demonstrating, on the one hand, that nothing can be taken for granted concerning the properties of an alloy of iron with other elements and, on the other, the power of systematic and co-ordinated research.

Another striking instance of the impossibility of predicting the properties of an alloy steel by analogy or deduction is to be found in the manganese-nickel-iron alloy "Resista," which was first described by the author in a paper read before the Mining and Metallurgy Section of the Engineering Conference held by the Institution of Civil Engineers in 1903.

The manganese-nickel-iron alloy "Resista" contains approximately 5 per cent. of manganese and 15 per cent. of nickel, and is particularly interesting in that it shows what extraordinary changes can be obtained in the soft metal by different alloys or combinations. A manganese-iron alloy containing about 5 per cent. of manganese and 0·45 to 0·50 per cent. of carbon is extremely brittle, indeed the cast alloy can easily be powdered under slight pressure and possesses the nature of a strong sandstone rather than that of an iron or steel alloy. Similarly, an alloy of iron with about 15 per cent. of nickel is brittle, though less so than the preceding manganese-iron alloy. The double combination of iron with 5 per cent. of manganese and 15 per cent. of nickel is, however, remarkably tenacious and ductile; in fact, the soft metal iron has its tenacity more than trebled and its elongation more than doubled by two elements which, when either of them is alloyed alone with iron in about the same percentages as in the double alloy, give products that are exceedingly brittle.

The principles of interpolation and extrapolation, so useful in some branches of science, are fatal to success in metallurgical investigation. Each alloy must be investigated completely and, if the labour entailed is increased by the impossibility of reaching conclusions by analogy, so too is the possibility of success, for an alloy of the highest practical value may be intermediate in composition between others which are commercially worthless.

During the past forty years the author has carried out correlated studies, which are the only real studies of value, on alloys of iron with manganese, silicon, aluminium, chromium, nickel, tungsten, cobalt, molybdenum, copper, titanium, and other elements. In almost every case these researches have covered and described methods of manufacture; chemical composition and analysis; properties of the metal as cast, and as rolled, forged, hammered, or pressed; heat-treatment; mechanical qualities, including elasticity, tenacity, elongation, and resistance to shock; hardness tests; microstructure; electrical and magnetic qualities; thermal conductivity; resistance to corrosion and erosion; and other properties where possible. In many instances it has been possible to submit samples of new alloys to specialists in various branches of scientific work who will, no doubt, agree that mutual benefit has resulted therefrom. Even in the earliest days of his metallurgical investigations—when materials, equipment, and knowledge were far from present-day standards—the author realised the importance of correlating as much information as possible concerning every new alloy, and the experience of forty years has but confirmed and strengthened this opinion. Data which at first appear to be of little interest, and that purely academic, may later prove to be of primary importance in explaining the properties of the steel, in assisting further research, or in relation to the practical requirements of a particular application. No one has laid more emphasis on the value of correlation in such researches as those relating to metallurgical investigation than Professor Arnold, F.R.S., to whom such great credit is due for the valuable life-long work he carried out on behalf of science.

Interdependence between Branches of Science.—Whilst referring to the subject of metallurgical research, mention may be made of a few instances in which this has derived assistance from new means of investigation provided from other scientific fields. In the author's Presidential Address to the Iron and Steel Institute in 1905 special attention was called to the metallurgist's indebtedness to the man of science. As an example, reference was made to the remarkable discovery of recalescence by that able scientist, Sir William Barrett, from which important results have accrued for the benefit of the science of metallurgy; (*see also* Chapter IX). This shows how a man of pure science, although himself not

a metallurgist, could render the greatest service to metallurgy. The accurate determinations of high temperatures, recalescence, and other critical points, have all been chiefly due in the first place to the man of science, and not to the industrial worker. This is but another proof of how necessary it is that the two factors of progress, Science and Practice, should go, as far as practicable, hand in hand, for, as exact laws are discovered by means of scientific research, so does the quality of our material knowledge improve, and the practical man is then able to apply the knowledge so gained.

The comparatively new method of examining crystal structure by means of X-rays, for which we owe so much to Sir William Bragg, has been of considerable value, and, particularly with regard to the metal iron, has thrown much light on hitherto obscure phenomena. A quarter of a century or so ago there were animated discussions before the Iron and Steel Institute and other scientific societies, on the vexed question of the critical temperature changes in iron, and their identification or otherwise with allotropic changes. Examination by means of X-rays, although somewhat belated as a means of settling the controversy, has in the true spirit of arbitration settled the question partly in favour of one school and partly in that of the other. Certain of the temperature changes are now proved to be associated with a definite change of crystal structure, while others are equally definitely dissociated from any such change.

Dr. Arne Westgren, of Stockholm, has carried out valuable researches regarding the structure of steel by X-ray examination, his results being described in papers contributed to the Iron and Steel Institute. He has also demonstrated the possibility of melting iron and other metals by bombardment with X-rays. High frequency currents of the type familiar in wireless telegraphy and telephony are already being applied successfully on a practical scale to melting purposes, a method which offers advantages from the point of view of clean melting, that is without contamination from unwanted ingredients.

It is also interesting to note that Professor C. F. Jenkin has made use of the thermionic valve as a source of power in the special type of apparatus which he has devised for fatigue testing. These examples serve to show that metallurgists, and those associated with them, are thoroughly up-to-date

in their methods of investigation. Also they demonstrate the important principle of interdependence between various branches of science.

Co-operation between Research Workers.—Next to correlation in research, principal importance must be attached to co-operation between research workers; this is, indeed, essential to a full realisation of the possibilities of correlation. A well-known scientific authority, Professor Farmer, F.R.S., said not long ago that, when judging the value and quality of research work, it should be borne in mind that every credit should be given not only for work done personally by the investigator, but also for what he inspires in others. The author ventures to hope that his research work has resulted in the accomplishment of both these objects.

In this connection the words of the late Professor Floris Osmond, the eminent French metallurgist and Bessemer Gold Medallist of the Iron and Steel Institute in 1906, may be quoted to show that, apart from the intrinsic value of the material itself, the research work carried out on manganese steel led to the introduction and examination of other new materials, and also directly and indirectly helped on the solution of many metallurgical problems. Professor Osmond said:—

> "The series of the Hadfield Alloys had been prepared with a degree of technical skill which upset many falsely conceived ideas, resulting from imperfect preparation or from faulty manipulation. Hadfield's method was a truly scientific one, by means of which all the independent variables which could be disposed of were eliminated. With the materials for investigation thus prepared, which for a long time had been unrivalled, the results obtained were at once clear, coherent, and definite. Moreover, Hadfield had not only made the best personal use of this wealth of material, but with never-failing generosity of which the writer had many times availed himself, he had placed it at the disposal of those inventors who were desirous of subjecting it to their methods and using it for their researches. Consequently, the useful results had rapidly gone on increasing, and from the accumulation of these the general laws had been evolved which formed the main object of all research."

Professor Osmond first wrote to the author in 1889, and from that time until the end of his life a regular correspondence was maintained. His help time and again on subjects of metallography, heating and cooling curves, pyrometric work, and other matters, was of the highest value, and he was kind enough to say that the many hundreds of specimens supplied

to him by the author proved to be of great assistance in his research work.

It may also be of interest to quote some remarks made by Professor Henri le Chatelier concerning the value of interchange of ideas and co-operation in research. He said, in the address delivered on the occasion of his Cinquantenaire Scientifique at Paris, on January 22nd, 1922 :—

> "As an example of mutual improvements I remember that after having instructed Osmond in the use of my thermo-electric couples, I learned from him the principles of microscopic metallography. The works of Sir W. Roberts-Austen, Director of the Royal Mint in London, inspired me with ideas, which are generally accepted to-day, as regards the constitution of alloys. It was through the inspiration of Sir Robert Hadfield, the scientific director of the Hecla Works, Sheffield, that I took up my researches on optical pyrometry. H. M. Howe and A. Sauveur, professors of metallurgy in the United States, opened my eyes, in the course of continuous correspondence, to the particularly interesting problems in the metallurgy of steel. We have continually collaborated in our investigations to such a degree that it has often been difficult to be sure which part has originated with a particular individual. Osmond and myself were never able to decide who was the first to compare the transformations of steel with the phenomena of solubility. One day we found ourselves completely in agreement on this point of view after an hour's discussion, at the end of which we found that we were left with ideas completely different from those which led up to the conversation."

These remarkable instances of the value of international co-operation deserve to be placed permanently and prominently on record, demonstrating, as they do, an experience which should be common to every research worker.

The present is a favourable opportunity for referring to the loyal co-operation which the author has always received from the members of his staff. It is almost invidious to mention names, but the author would specially like to refer to some of them. Amongst those, alas, gone before, are the names of Mr. E. Wheatcroft, an able chemist of earlier days, also Mr. John Mallaband; and of those who are happily still with us, the names of Mr. A. M. Jack and Mr. P. B. Brown, Major A. B. H. Clerke, Commander E. H. M. Nicholson, Messrs. Burnham, Crabtree, Crosbie, Cross, Cutts, Dawson, Elliot, Ellison, Main, Milne, Ott, Parker, Sarjant, Stevenson, Turner, Rodgers, Willey and others.

On the clerical side, including the recording of experiments and classifying them, that is, general secretarial work, not an unimportant part of research, the author has been indebted

for help, cheerfully rendered often under difficult circumstances, to Messrs. Hemsoll, Mortimer, Heeley, Hallatt, Rowland, and many others who came later. It may be interesting to add that Mr. Hemsoll assisted the author in acquiring a knowledge of shorthand, which in his busy life he has found invaluable—in fact, it would have been impossible to get through the large amount of work he has done without the aid of shorthand. The author gladly bears testimony to the work of that great man Sir Isaac Pitman, who invented the wonderful system of rapidly putting down on paper not words merely, but thoughts.

Mr. T. P. O'Connor recently stated before the "To-morrow Club," which was discussing whether success was merely a fortuitous occurrence or not, that he got his first job not by Greek or Latin, by French or German which he had studied, not by his knowledge of history or his knowledge of literature, but because he had learned to write shorthand.

Endowment of Research.—Though many of the most important discoveries of the past have been made with the simplest apparatus—used, of course, by men who had natural gifts of intellect, observation, and imagination—the number of fundamental discoveries remaining to be made has been reduced, and the research work of to-day demands more in the way of equipment, physical and mental, than was formerly the case. Doubtless there are some, perhaps many, "fundamental" discoveries which will still be made with little apparatus; but, on the whole, modern precision research work demands experimental facilities which would have astonished, as much as they would have delighted, such men as Boyle, Priestley, Watt, and Faraday. The intelligent and productive use of such facilities demands, besides natural gifts, a special course of training, and all of these facilities—both material and educational—involve comparatively heavy expenditure.

Time and labour must be given by the research worker himself, but the educational facilities and the laboratory equipment which he needs are ready to hand on a scale and to a degree which lie far beyond the resources of the individual worker. For these facilities we are indebted to the munificence and public spirit of our great Institutions and Societies as a whole and, particularly, to those individual benefactors whose labours have inspired, and more or less actively assisted,

the foundation of research laboratories and research fellowships.

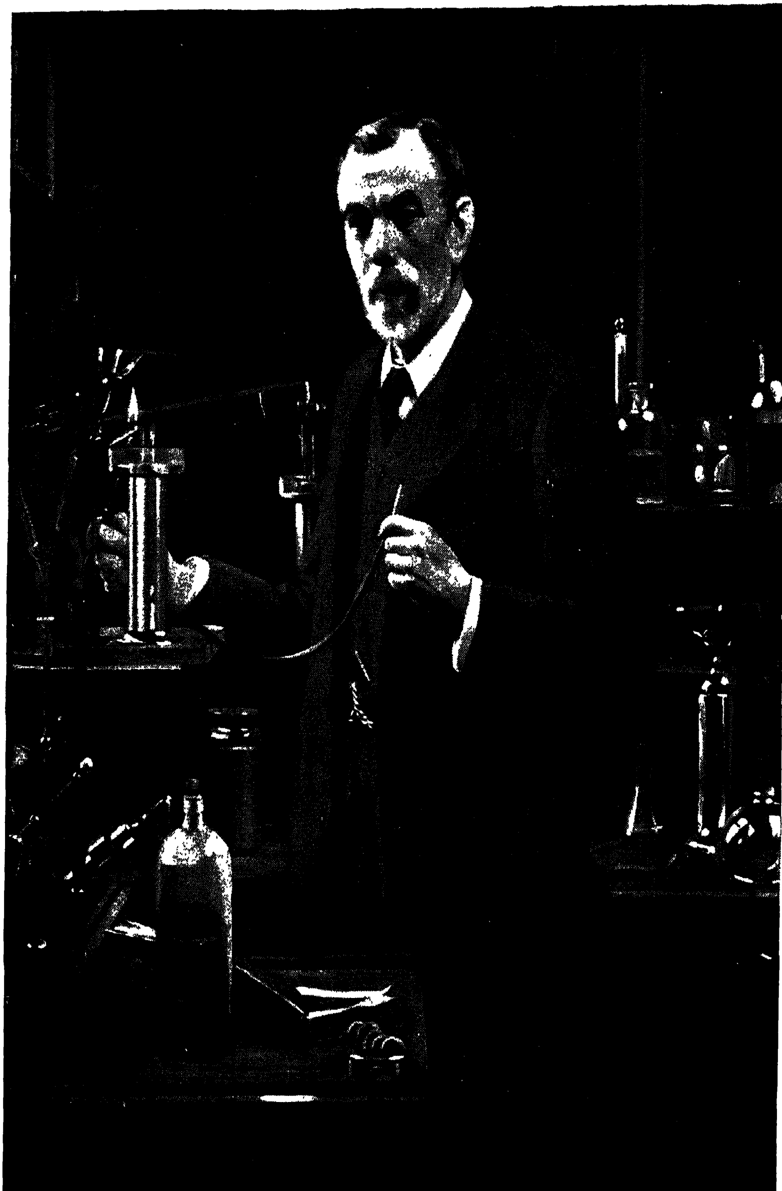
Ramsay Memorial Fellowships.—As one of the Trustees of the Ramsay Memorial Fellowship Trust, the author has pleasure in calling attention to the useful work being done by this body. In a speech not long ago, Sir Gregory Foster, Provost of the University College, mentioned that the sum of £54,000 had been raised in this country in memory of this great Englishman, Sir William Ramsay. To this should be added the value of the Fellowships contributed by the Dominions and foreign countries.

Ramsay's name is inseparably associated with the progress of chemistry during recent times—whether on a national or a world-wide basis. For thirty-five years he occupied a foremost place in the ranks of scientific investigators, and his discoveries in the realm of chemical science earned for him a world-wide reputation. His portrait is shown in Plate LXIX. Born in Glasgow in 1852, he studied at Glasgow University, at Heidelberg, and at Tübingen. During the period 1880–1887 he was Professor of Chemistry at University College, Bristol, and subsequently until his retirement in 1912, he held the corresponding position at University College, London.

His discovery of argon arose from an investigation to determine why the density of chemically-prepared nitrogen differed from that of the supposed pure nitrogen extracted from the air. The reason lay, of course, in the fact that the atmospheric nitrogen contained some argon, and this research affords a striking instance of the importance of observing small differences or discrepancies and ascertaining their cause. Argon, which is present in the atmosphere in such a small proportion that its existence had been overlooked by all previous workers, is now used industrially in gas-filled electric lamps.

Continuing his researches Ramsay discovered other rare elements, namely helium, krypton, neon, and xenon, and in his later years he demonstrated the transmutation of radium into helium—the twentieth century realisation, in some degree, of the mediæval Philosopher's Stone.

The work of the Ramsay Memorial Fellowship Trust has consisted of two principal features, one being the establishment of a number of Fellowships for British Chemists tenable in any University or College in the United Kingdom. The



PORTRAIT OF THE LATE SIR WILLIAM RAMSAY.
(By Mark Milbanke).

(By permission of the Committee of University of London University College.)

second is the establishment of Fellowships by the Dominions and foreign Governments.

The Trustees are now administering sixteen Fellowships, including three temporarily vacant. These include General Fellowships, Glasgow Fellowships, also Greek, Italian, Japanese, Canadian, Swiss, Norwegian, Swedish, Danish, Dutch, Spanish, and French Fellowships.

Important researches are being carried out, one of which is of special interest to metallurgists, namely that made under the French Fellowship awarded to Dr. H. Weiss, of the University of Paris, just appointed to a Lectureship in the University of Strasbourg, who has been working under the direction of Professor Sir William Bragg at the Royal Institution, on the study of the application of X-ray analysis to the metallurgy of alloys.

The Fellowships have undoubtedly justified themselves, although there is ample scope for the extension of the scheme if the funds administered by the Trustees were larger. It would also be desirable to increase the value of the Fellowships. Reference to the efficacy of these Fellowships in promoting international co-operation and good will is made in Chapter XVI.

Yarrow Gift for Endowment of Research.—As another example of endowed research, mention should most certainly be made of Sir Alfred Yarrow's magnificent gift of £100,000. The Council of the Royal Society has decided to use the larger part of the income in the direct endowment of research by those who have already proved that they possess ability of the highest type for independent research. To this end a number of Professorships will be originated, of a type similar to the Foulerton Professorships, which were founded by the Society in 1922 for research in medicine.

The Professors will be expected to devote their whole time to scientific research, except that they may give a limited course of instruction in the subjects of their research to advanced students. By thus ear-marking research as a definite profession, the Royal Society have wisely established a policy which must be of the greatest possible service to this country.

Carnegie Research Fund and Scholarships.—As a member of the Carnegie Scholarships Committee of the Iron and Steel Institute, the author can bear testimony to the

immense good resulting from this great man's munificent benefactions, not only to America but to this country as well. In this country he gave handsome help to the Iron and Steel Institute, of which he was President immediately before the author's year of office, including the large sum of \$100,000 to found the Carnegie Research Fund and Scholarships. Ever since 1901 this benefaction has done untold good in encouraging metallurgical research irrespective of nationality or sex. When the Scholarship Paper presented is considered of sufficient merit, the candidate is awarded the Andrew Carnegie Gold Medal.

Iron Alloys Research Committee.—Another important development in the provision of facilities for research was the formation, in 1922, of the Iron Alloys Research Committee as an offshoot of the old Alloys Research Committee which originated in 1889 at the instance of the Institution of Mechanical Engineers. It has been the author's privilege to be associated with the old and the new Committees over a period of thirty-three years, during which time the members have included those noted for their knowledge and research on alloys. The information gained has been of great service to the country, including the reports of the late Sir William Roberts-Austen, F.R.S., Dr. W. Rosenhain, F.R.S., and others.

Upon the reconstitution of the Committee, in 1922, it was decided to devote attention for the present to alloys of iron only. Sir John Dewrance, the Chairman of the former Committee, was reappointed to that post, and the other members co-opted were Sir Thomas Kirk-Rose, Professor H. C. H. Carpenter, F.R.S., Mr. Harbord, and the author.

It should be mentioned that the Council of Scientific and Industrial Research is generously assisting these important investigations. The Royal Society, the Institution of Mechanical Engineers, the Iron and Steel Institute, the Armourers and Braziers Company, Sir John Dewrance, and Messrs. Babcock and Wilcox, have also each contributed £500. Some of these have since doubled their donation. It may be added that at the Autumn Meeting of the Iron and Steel Institute in 1924, a valuable paper was read by Dr. Rosenhain entitled "Ferrous Alloys Research," describing in a most interesting manner that portion of the research work already carried out.

As more funds are required, it is hoped that further generous donors will come forward and assist the efforts being made by the Chairman and his colleagues in this important work, which is a welcome indication that this country intends to keep ahead and maintain, as in the past, its position as pioneer of metallurgical knowledge.

Industrial Research in the United States.—As might be expected, we are not alone in our appreciation of the importance of research for, in the United States alone, there are about 500 different laboratories, many of the most important being in industrial establishments.

One of the greatest living scientists, Sir Joseph J. Thomson, Past President of the Royal Society, paid a visit to America a few years ago, and went through the Research Departments of some of the large manufacturing firms just mentioned. Whilst these laboratories have often been established in the face of considerable opposition, it is now generally admitted that the Research Department, even from the monetary point of view alone, is one of the most profitable possessions of manufacturing concerns. Moreover, however great the necessity for economy may at times prove to be, the cost of the research side of the work should be the last to be reduced.

Sir Joseph has pointed out that the scale of the laboratories in the United States is far greater than anything in Great Britain, and much of the work carried out is fundamental scientific work, worthy of a University Laboratory. On the other hand, he says the American Universities do not seem designed to produce a large number of men qualified to take up advanced research work, and mentioned that few of the science students have the necessary equipment in mathematics, and the stern training which a good honours man in a great English University has to go through appears to be unknown. The system may be good for the average man, but a successful Research Institute requires something more than the average man; it needs men with high scientific knowledge. In this respect, Sir Joseph states Great Britain has a distinct advantage in the competition which is before us. Coming from such a high authority this indeed is satisfactory.

To show the attention being paid in America generally to the subject of research, it is interesting to note that a new building is now being erected in Washington, close to the

famous Lincoln Memorial, for the National Academy of Science and the National Research Council. The total cost is to be about £300,000.

The important encouragement given to research by the Research Narratives, issued by the Engineering Foundation of the United Engineering Society of America, has already been mentioned in Chapter XIV.

Japanese Research Institute for Iron, and Steel and Other Metals.—The marvellous changes which Japan has undergone during the past two generations have been startling in number, variety and degree. Within the memory of many still living, Japan maintained customs and institutions resembling those of Europe in the days of feudalism, and Science was practically unknown there. Now, however, the industries of Japan compete with those of the West, and Japanese investigators have made scientific contributions of no mean order. As showing that the Japanese nation intends to encourage strongly and to develop the science of metallurgy it may be mentioned that the Research Institute illustrated in Plate LXX is devoted to the investigation of iron, steel and other metals, and is the only one exactly of its kind. For most of the following information concerning this important Institute the author is indebted to his friend, Professor Kotaro Honda of the Tohoku University. From time to time Professor Honda, Professor Kaneko, and Professor Akutsu have visited the works and research department of the author's firm in Sheffield, and all of these gentlemen have showed most active and intelligent interest in the progress of metallurgy. The Bessemer Gold Medal for 1922 was awarded to Professor Honda by the Iron and Steel Institute in recognition of his distinguished services in the science of iron and steel.

The present Research Institute for Iron, Steel and other Metals at Tohoku originated in the provision made during the early years of the Great War for investigations concerning the self-supply of materials needed by Japan, and concerning the physical study of steel. In August, 1919, it was announced, by Imperial Ordinance No. 229, that the Research Institute for Iron and Steel was attached to the Tohoku Imperial University, having two research professors, five assistant professors, and five assistants, the annual current expenditure to be 37,000 yen, which was afterwards increased to 50,000 yen. This formed the first step in the extension of the

THE JAPANESE RESEARCH INSTITUTE.

Institute, and Professor Honda was appointed Director. In July of the same year, Take Sone, Takejiro Murakami, and Torajiro Ishiwara were appointed assistant professors, and in October, 1920, Mitsuo Yamada was appointed assistant professor, all having additional responsibility for the Research Institute for Iron and Steel.

The previous generous donor, Baron Kichizaemon Sumitomo, who had already contributed 21,000 yen to the second department of the Institute, the chief object of which was the carrying out of various physical investigations, again contributed 150,000 yen for the building expenses, 100,000 yen for the equipment expenses, and 50,000 yen to supplement the current expenditure for three years, totalling 300,000 yen.

The building of the Institute, which had been in progress since 1919, was completed in April, 1921.

The following are the stipulations of the Imperial Ordinance :—

> *Art. I.* To the Tohoku Imperial University shall be attached the Research Institute for Iron, Steel and Other Metals.
>
> *Art. II.* The Research Institute for Iron, Steel, and Other Metals shall have charge of the study of the theory and the application of iron, steel and other metals as well as of various alloys.
>
> *Art.* III. The Research Institute for Iron, Steel, and Other Metals shall have the following three departments : Metallurgical Department ; Steel Manufacturing Department ; Foundry Department.

The expenditure of the Institute for 1923 was 124,700 yen, and the fund is to be continued for three years.

The building of the Institute consists of the main building and attached workshops, shown in Plate LXX. The main building is a three-storied brick structure, including the basement, having 21 apartments.

The Institute has various equipments for the study of both theory and practice, and the number of apparatus, machines and instruments amounts to about 700. In the main building there is an X-ray apparatus, an excellent metallographic installation including apparatus of the Leitz and Reichert types ; apparatus for the measurement of electrical resistances, thermal expansion, specific heat, the heat conductivity of refractory materials, elasticity and rigidity, thermo-balance, thermal, magnetic and chemical analyses, and other instruments for various physical, chemical and metallographic investigations.

For the study of various phenomena at low temperatures there are an ammonia refrigerator and a Linde air-liquefying machine to enable work to be done at temperatures down to −180°C. For testing materials there are an Olsen 30-ton machine; Charpy impact machine; Matsumura, also an American-made continuous impact tester; Brinell hardness tester, and other equipment. For melting metals and alloys, a kryptol electric resistance furnace, a Tammann carbon resistance furnace, a metallic wire resistance furnace and various other electrical and gas furnaces, to provide for making samples of a small quantity for experiment. The foundry is provided with a 300–kg. cupola furnace, a 200–kg. cupola furnace, a Roots blower, a drying furnace, a coke crucible furnace, a gas furnace, a 300–kg. Gronwall electric furnace, also a 30–kg. Héroult electric furnace. There is also a wood workshop which is fitted for making models of various designs and instruments. The forge equipment includes a heating furnace, an annealing furnace, an air hammer, and a roller, used for forging and rolling. In addition there is a 2-ton crane. In the machine shop there are various machine tools such as lathes, shapers, drills, milling cutters, grinders, for preparing various samples for study, also for making and finishing various instruments. The Library possesses about five hundred books on metallography, metallurgy, physics, chemistry, etc., and about twenty-five important foreign journals, as well as Japanese journals and reports.

The following are some of the subjects of investigation at this Research Institute :—Studies of light alloys ; studies in sand and moulding ; hardness at high temperatures ; relation between the phase diagram and the magnetic susceptibility ; determination of the solidus lines in the iron-carbon system ; the melting-point depression in solid solutions ; phase diagram of Al–Cu–Ni ; cementation process ; forging temperature of steels ; phase diagram of Fe–Mo–C ; phase diagram of Fe–Mn–C ; X-rays ; gas absorption by metals ; brittleness of metals at low temperatures ; studies of cement and concrete ; ductility of metals ; phase diagram of Fe–Ni–C ; measurement of thermal and electrical conductivities ; change of modulus of elasticity by magnetisation ; formation of spheroidised carbide in steels other than carbon steel.

As regards the research work carried out since 1912, there have been published 108 papers on various metallurgical subjects.

In conjunction with the Research Institute is established the Kyoyukai Society (*kyoyu*, to melt together), which aims at social intercourse between members as well as promoting and developing the knowledge of iron, steel, and other metals. This Society is formed by the staff of the Research Institute, those connected with the Institute, also those introduced by them and permitted entrance by the Board of Directors.

Suggestions for Research.—One of our foremost political leaders, himself a scientist, the late Lord Salisbury, has well said: "We live in a small bright oasis of knowledge surrounded on all sides by a vast unexplored region of impenetrable mystery, and from age to age the strenuous labour of successive generations wins a small strip from the desert and pushes forward the boundary of knowledge." The progress of science during the past century has been remarkable, but we are still far from the ultimate boundaries of knowledge. To the observant man—and no other can succeed in research work—there are countless opportunities for scientific investigation, discovery, and invention.

In his recent Presidential Address to the Institution of Electrical Engineers, Mr. W. B. Woodhouse pointed out that the electrical industry, like all other human organisations, is changing and must change if progress be made. The changes will be brought about largely by the abilities and inventive powers of engineers—or, speaking more broadly, by scientific workers in general—hence it is particularly important that the younger men "should not be overawed by the magnitude of the work done in the past, but should preserve that spirit of adventurous research which the pioneers of the past possessed in so great a degree." These wise words of advice and encouragement hold good in every field of pure and applied science.

The author was recently asked by the Institute of Patentees to put down in their book, entitled "What's Wanted," any suggestions which occurred to him concerning "Things which Require Inventing." In this book there are already most interesting suggestions, such as the following:—A cinema film that will speak; a method of utilising atomic energy; a process for instantaneous colour photography; a method of conveying speech direct and readably to paper; a means of regulating the rain supply, or a means of inducing and preventing rain; the discovery of the mechanism which

enables us to remember almost instantly in our brains without going through the mechanism of the card index and equivalent systems.

As regards the cinema film of speech, a valuable Lecture entitled "Talking Motion Pictures" was given by Mr. C. F. Elwell on this subject before the Royal Society of Arts on November 26th, 1924, in which this was actually carried out. The audience heard an excellent speech delivered by President Coolidge, who seemed almost present in the flesh on the screen, and his voice was certainly there in facsimile. Many other examples were presented: altogether a most interesting performance.

The Right Hon. Sir William Bull, Bt., M.P., who has taken considerable interest in the Institute of Patentees, says with regard to their suggestion book: "Some of the ideas which will appear may seem fantastic, but the miracles of one decade are the commonplace of the next. It may be that an idea written in this book will give a flash of inspiration to an inventor which will alter the history of the world. This may sound extravagant, but time will prove its truth." With these opinions the author is in entire agreement, and he has added the following "wants" to the suggestions already in the book:—

(1) An alloy, ferrous or non-ferrous, possessing 50% to 100% higher tenacity than any known combination, whilst at the same time not being brittle. If such a want were met, mechanical constructions of all kinds would be largely modified and improved.

(2) Some form of lighting appliance capable of penetrating fog. This would meet a very great need.

(3) Refractory materials for the lining of steel melting furnaces and ladles that would be absolutely unattacked by erosion of the molten steel, or corrosion of the various metallic oxides formed during the steel melting process. There is a great want for improvement in this direction.

(4) A safe method of stopping steamers and ships from rolling, or at any rate not more than a few degrees, in the roughest weather.

The Field for Metallurgical Research.—In the field of science with which the author has been principally concerned, that of alloy steels, much has been discovered during the past forty years, but in all probability far more remains to

be learnt. As pointed out in his paper on "The Development of Alloy Steels," presented to the Empire Mining and Metallurgical Congress in 1924, there are many elements the effects of which on iron in binary alloys (one other element with iron) have still to be investigated, and the number of ternary and quaternary alloys awaiting investigation is naturally much greater.

Arranged in order to atomic weight, the elements which have been more or less thoroughly investigated in relation to their effects on iron are as follows:

Boron, carbon, aluminium, silicon, phosphorus, sulphur, titanium, vanadium, chromium, manganese, nickel, cobalt, copper, arsenic, zirconium, molybdenum, silver, tin, cerium, tantalum, tungsten, bismuth, uranium. Total binary alloys, 23.

It will be seen that this list does not include gaseous elements, such as hydrogen, nitrogen, and oxygen, or magnesium, calcium, mercury, and lead, which do not alloy with iron, or any of the remaining 54 elements of which little is known concerning their effects on iron.

Confining ourselves to the 23 elements mentioned in the above list of binary alloys, the number of possible ternary alloys (two other elements with iron) is 253, and the number of possible quaternary alloys (three other elements with iron) is 1771. The total number of possible ternary and quaternary alloys is thus 2024, using only the 23 elements mentioned, and the complete investigation of this field will inevitably occupy many years. There is little or no possibility of predicting results by analogy, interpolation or extrapolation. Intelligent anticipation may be of considerable assistance, but certain knowledge can only be derived from a complete scheme of correlated research.

Contemplating the figures given in the preceding paragraph, and notwithstanding the remarkable present-day development of special steels, one is reminded irresistably of the words of Cecil Rhodes: "So little done, so much to do."

Nevertheless, it is very necessary to do that which at present remains undone in the field of alloy steels. Completeness of scientific knowledge and the innumerable requirements and possible applications in modern industry alike demand that every possible alloy should be investigated—and investigated fully.

Though an alloy steel may appear to be of no practical value

as judged by the results of the more common tests—for example, the measurement of tensile strength, elongation, ductility, and shock-resistance—it does not follow that the alloy is actually worthless. On the contrary, it may be of the utmost value in some special application now or in the future, and there is no excuse for omitting to investigate and record the properties of the material to the fullest possible extent.

When we are tempted to regard a new alloy as worthless or unimportant, let us remember how often it has been necessary to reverse an initial condemnation of this kind. Fresh knowledge and fresh requirements continually bring to light fresh opportunities, and it is evident that the French chemist, Vauquelin—who laboured so industriously during the troublous years of the French Revolution—was thinking on these lines when he said (concerning his discovery of chromium): "I venture to say that if chemistry could only utilise but a few of the many objects that Nature offers to us, it would soon convert into useful applications bodies which now exist only as a vain curiosity." Even in the twentieth century the "vain curiosity" of to-day may be the useful alloy of to-morrow.

In the non-ferrous branches of metallurgy there are equally great opportunities for research and, in this connection, mention may be made of the valuable Presidential Address delivered by Dr. W. R. Ormandy to the Institution of Automobile Engineers in October, 1924. Therein Dr. Ormandy gives credit to the ferrous metallurgist for the enormous amount of work he does in investigating alloys of iron with other elements. He says "A hundred years of work on the alloys of iron, particularly with carbon, but almost always in the presence of silicon, manganese, sulphur, and phosphorus, have led to the production of products answering a vast field of requirements." He then goes on to say that he trusts that similar attention will be given to non-ferrous alloys, and that for example "the amount of investigation which has been devoted to aluminium is a negligible fraction of that spent on iron and its alloys. The amount of work which remains to be done upon aluminium and magnesium alloys becomes obvious when we consider what has been done in the case of iron."

The Study of High Temperatures.—Of the many directions in which a practically unexplored field still lies before the investigator special mention may be made of the study of high temperatures and their effects.

Few can speak on this subject with greater authority than Dr. E. F. Northrup, of Philadelphia, Pa., who has done such excellent work in this respect, and whose research work and practical application of high frequency melting furnaces in which very high melting temperatures are readily obtained has been of the greatest value to metallurgists. Many of the most important problems of the day in producing special alloys have been solved by the aid of this high frequency melting furnace of his.

In a paper read before the Franklin Institute some time ago, Dr. Northrup stated that no path goes straighter or quicker to discoveries which will add so much to our knowledge of matter itself, and to the finding of things useful for every-day life, than the roadway of high temperature investigation.

He says that while not underrating the great value of low temperature research on the properties of matter—by such research we have penetrated deeply into a further understanding of its constitution—the upper limits of the temperature scale are now attracting more attention, for there matter pulsates with mighty energies. It takes on aspects and strange qualities that fascinate, and the hope is ever held out of discovering in the region of high temperature unsuspected properties of matter extremely useful in the every-day affairs of industry, with a view to increasing the comfort and convenience of life.

Our store of quantitative knowledge, embodied in tables of constants, of the physical and chemical properties of matter above 1500° C. is small indeed. Outside its property of giving off radiant energy, physicists and chemists have paid little attention to a quantitative examination of the properties of matter exhibited at the higher temperatures. High temperature makes of most kinds of matter something which is entirely new ; something unrecognisable as the same stuff with which we started at ordinary temperature. What undreamed-of beneficent uses may not matter possess in this new dress, put on with *fire !*

Dr. Northrup further says that by passing to the highest temperatures there is eliminated from consideration all such phenomena as crystallisation, magnetism, surface colouring, production of aqueous solutions, the greater part of the phenomena of organic chemistry, and a multitude of other familiar physical and chemical manifestations. The science of biology outside the range of ordinary temperatures is non-

existent. Life does not seem to exist below about $-50°$ C. or above 100° C.; that is, living organisms are only maintained in the form we term "life" within the narrow range of about 150° C.

When nature is studied, simplified, so to speak, we should be able to acquire a better understanding of the increasingly complex phenomena which appear as we bring the lower temperature range up and the higher temperature range down. In the light of our knowledge of nature simplified we shall be better able to interpret her more complex manifestations at ordinary temperatures.

Although Dr. Northrup's remarks are intended to refer to physical and chemical research on matter in general, they remain true if applied more specifically in connection with metals. Indeed it is largely the requirements of the iron and steel industry which have been responsible for the improvements in apparatus and methods for high temperature measurement.

In this connection it is interesting to recall the pioneer work of Josiah Wedgwood, F.R.S., 1730–1795, who was born at Burslem, Staffordshire (*see also* Chapter XI). He was one of the first to grasp the importance of understanding and accurately determining high temperatures. The fact that he was elected a Fellow of the Royal Society is proof that his work was appreciated. Later developments have sprung chiefly from the scientific work of Professor Henri le Chatelier, F.R.S., in France, and of Professor H. L. Callendar, F.R.S., in England.

To show how limited is our experience of high temperatures reference may be made to a most instructive article by Herbert Dingle in "Nature" on "The Temperature of the Stars." According to Mr. Dingle these are exceedingly high; for example, that of Vega has been stated to be 12,000° C., Pegasi 22,000° C., and Persei no less than 28,000° C. He also states that according to important authorities, it is quite probable that there are bodies in the universe at all temperatures between absolute zero and twenty million degrees Centigrade or even higher!

Metallurgists on our earth find that 1,500° C., that is, about the melting-point of iron, is quite hot enough, but temperatures some twenty times or even some ten thousand times as high appear to exist in the universe. These figures can hardly be grasped by the human mind. Even the Sun's temperature of 5,300° C. pales into insignificance.

As regards mundane heat, volcanoes in eruption show high

temperatures, but apparently not more than about 1,600° C. To a metallurgist it is hardly possible to conceive a more beautiful attempt to depict the different colours and the shades of high temperatures than that shown in the wonderful picture *Mount Vesuvius in Eruption in* 1818, painted by that renowned British artist, J. M. W. Turner, R.A. The beautiful tones in this water-colour picture, which is in the author's possession, range from dull red to white heat, that is they include temperatures from about 600° C. to 1,600° C. and are depicted in a marvellously artistic manner. Of course it may be that under high pressures in the bowels of the earth temperatures are much higher, but we have no direct evidence to this effect, and no known refractories will withstand much greater temperatures than about 1,800° C. without fusion.

The Development of Discoveries and Inventions.—Inspired though he be by a genuine desire to acquire knowledge primarily for its own sake—and this desire must be predominant if success is to be attained—the research worker naturally hopes to discover facts and principles of some commercial value. In this connection, however, a double warning may be offered to the younger men among us, firstly not to allow the desire for commercial success to become predominant, and secondly not to be disheartened by the long time which so often elapses before any commercial return can be secured from a discovery or invention.

Workers, whether scientific or practical, none too well paid in the first instance, may be excused for feeling impatient and even bitter as the best years of their lives pass away and any patents which they may hold shorten their term—or possibly expire—before adequate monetary return is secured, but, even under these trying conditions, to become discouraged is merely to add to the difficulties of the situation, and still further delay commercial success.

Amongst the many obstacles to be overcome are the apathy of the public and—generally more serious and always less excusable—the shortsightedness, prejudice, or ignorance of those in responsible positions.

Take, for example, Watt. He was once informed by Sir Joseph Banks, President of the Royal Society, that "Your plan is a pretty one, but there is just one point overlooked: that the steam engine requires a firm basis on which to work."

Shortly after the publication of his first researches in

magneto-electricity, Faraday attended the meeting of the British Association at Oxford in 1832. On this occasion he was requested by some of the authorities to repeat the celebrated experiment of eliciting a spark by means of magnetic induction, employing for this purpose the large natural magnet in the Ashmolean Museum. To this he consented. and a large party assembled to witness the experiments, which, needless to say, were perfectly successful.

Whilst he was repeating them, a dignitary of the University entered the room, and addressing himself to Professor Daniell, who was standing near Faraday, inquired what was going on. The Professor explained to him as popularly as possible the striking result of Faraday's great discovery. The Dean listened with attention and looked earnestly at the brilliant spark, but a moment after he assumed a serious countenance and shook his head: "I am sorry for it," said he, as he walked away; in the middle of the room he stopped for a moment and repeated, "I am sorry for it"; then walking towards the door, when the handle was in his hand he turned round and said, "Indeed, I am sorry for it, it is putting new arms into the hands of the incendiary!"

Later on, Dr. Lardner delivered a Lecture before the Royal Institution "proving" that steamers could never cross the Atlantic because they could not carry sufficient coal to raise steam for the voyage, yet that same year, 1838, the *Sirius* of London left Cork for New York and made the passage in 19 days; and the *Great Western* steamed from Bristol to New York in 13 days. Both of these vessels were steamers, and reliance was not placed upon the sails.

Amusing though such instances may appear to us, they are typical of one of the difficulties which has beset almost every great scientific advance. Narrowness of view, lack of sympathy, and failure to understand may be responsible for many incidents which give rise to mirth in later years but, at the time, they may discourage the discoverer or inventor and possibly retard progress to an appreciable degree. The subversive criticisms formerly levelled at the motor car, the aeroplane, the electrically propelled ship, and other modern inventions suggest that, even to-day, criticism may easily fall behind—and tend to retard—the march of progress.

On the question of difficulties in the commercial development of scientific discoveries the author is able to speak from personal

experience, for many serious obstacles had to be overcome in perfecting the manufacture and securing the practical application of manganese steel and silicon steel. The original patent relating to manganese steel was taken out in 1882, but no extensive sales were secured until 15 years afterwards, and in the case of silicon steel the period of development was even longer—from 1884 to 1906, or 22 years! Meanwhile there had been an expenditure of time, labour, and money which it is impossible to assess.

At the time of its discovery there may be little or no field of application for a new alloy steel, and, for a variety of reasons, the rate of development in the use of a new steel may be disappointingly slow. In his paper on "Alloys of Iron and Chromium," read before the Iron and Steel Institute in 1892, the author said: "When it is borne in mind through how many difficulties the metal known as carbon steel has had to struggle, and for how long a period it has had to undergo trial and examination, it is not surprising that the introduction of special combinations, such as manganese, nickel, and chromium steel, takes place but slowly." These and many other alloys have now come into their own, but the advance has not been easy; and the above words, written more than thirty years ago, still hold good so far as concerns the severity of the trials which any new alloy must undergo before it can be accepted as a useful addition to the list of known metals.

Many other instances might be cited to demonstrate the vast difference in point of time between discovery and application. Thus in an Address on "A Hundred Years of Electrical Engineering," delivered to the Engineering Section of the British Association at the Toronto meeting in 1924, Professor G. W. O. Howe, D.Sc., says that if any one event can be regarded as the birth of electrical engineering it is surely the discovery by Faraday, in 1821, of the principle of the electro-motor; that is, that a conductor carrying a current in a magnetic field experiences a force tending to move it. It is noteworthy that ten years elapsed before Faraday discovered, in 1831, magneto-electric induction; that is, the principle of the dynamo. Four years later, Sturgeon added the commutator or "unidirective discharger," as he termed it; and in 1845 Cook and Wheatstone used electro-magnets, which Sturgeon had discovered in 1825, instead of permanent magnets. It was during the years 1865–1873 that the shunt and series self-

excited dynamos, using a ring or drum armature and a commutator of many segments, finally evolved. The early workers in the field do not appear to have realised the intimate connection between the dynamo and the motor, for, although the principle was discovered by Lenz in 1838, it only appears to have become generally known that the same machine could be used for either purpose about 1850. The principle underlying the whole modern development of electrical engineering—viz., the generation of electrical power by dynamo, its transmission to a distant point and its retransformation to mechanical power by an electric motor—appears to have evolved about 1873.

In the words of the late Professor S. P. Thompson, Faraday's great discovery of 1831 notwithstanding, the real significance of the dynamo had not yet (in 1857) dawned upon the keenest minds of the time.

The full development of what must first be a " brain wave " or brief flash of knowledge often takes, as it seems to human beings, an extraordinary long time. The author's object, in referring to this outwardly depressing fact, is to emphasise that its true lesson is the importance of courage and perseverance. Despondency will never mend matters, but vigorous and sustained effort, combined with active interest and alert observation, will inevitably result in accelerated progress.

Nevertheless, in view of the time and effort required to bring the majority of discoveries and inventions to commercial fruition, it is eminently desirable that scientists should be able to protect their rights in scientific discoveries in the same way as musicians and authors can copyright their creations. Granted such facilities, in conjunction with lower patent fees and a longer period of protection, scientists would be encouraged to devote more attention to the industrial application of the results of their researches, and patentees of all classes would be better able to afford the direct and indirect costs of the period of development. A wise and cheap patent law is of the greatest benefit to a nation and, in this respect, the United States are without doubt much more favourably situated than ourselves.

PART V—THE FUTURE

CHAPTER XVI

THE FUTURE.

Effort and Progress.—The turmoil of modern life and those uncertainties which are the aftermath of the Great War cannot obscure two vital facts, namely, the importance and rapid progress of science, and the necessity to strain every effort, national as well as individual.

As pointed out by a writer in *The Humanist*, in September, 1924, the civilisation of Europe, until a few hundred years ago, was behind the Asiatic civilisation, dating three thousand years earlier. Probably it is less than three hundred years ago that English mentality reached the intellectual level of the ancient Greek and Roman civilisations that produced Aristotle and Plato; and only within the last hundred years have we, through scientific research, made any real progress beyond the point which previous civilisations had already reached. It is, however, probable that the results of all past culture will be excelled by the advance of the next hundred years.

The old days of mysterious alchemy and rule of thumb have gone for ever, and science blazes its trail through the unknown, conquering little by little, and adding ever in increasing ratio to our stock of knowledge. If this progress is used for the general benefit of mankind, then the world must surely be a better place in which to live. The discoveries of science are shared by all, from the lowest to the highest.

War Waste and Imperial Resources.—During the years 1915–1919, the Ministry of Munitions spent on munitions and materials, including advances to contractors and capital expenditure, the colossal sum of £1,858,213,180. Some idea of what this figure means may be gathered from the fact that this amount would have purchased over 600 million tons of pig iron at the pre-war price of £3 per ton; also assuming the world's output of pig iron to average 50 million tons per annum it would have taken all the blast furnaces in the world twelve years to produce this quantity of metal.

This expenditure, gigantic as it is, forms a comparatively small portion of the total sum expended by this country, irrespective of that by our Allies. Seeing that practically all the value covered by the figure relating to munitions was blown into the air, it is no wonder that the world—employer and employed, victor and vanquished alike—has not yet recovered from this terrible waste.

On the other hand, though the war has been such a great strain upon us, the outcome is that we are more powerful, stronger, and possess still greater resources than ever. The addition to the territories coming under the control of our Empire since November, 1918, has been enormous. Let us but shake off the mental and physical apathy which still impedes our progress, and tackle with our fullest energy the realities of the situation. Developments of all kinds will then result in increased prosperity and greater comfort to all concerned.

We are the greatest nation ever known under one flag. Of about 52,000,000 square miles of land on the earth the British Empire controls about 14,000,000 square miles, or considerably more than one quarter of the world. These facts and all that they imply were demonstrated as never before by the British Empire Exhibition.

The British Empire Exhibition.—So wide was the scope of this remarkable Exhibition that it was difficult to realise it represented the resources of our Empire alone. The educative value of the Exhibition in driving home this fact was immense and will, the author ventures to believe, be increasingly apparent in years to come. About one million school children visited the Exhibition during the period April to October, 1924, and the effect produced upon their impressionable minds may prove ultimately to be of even greater importance than that produced upon their elders.

As a comparison it may be mentioned that the Great Exhibition of 1851, held in London, was open for about 23 weeks and was visited by 6,170,000 persons. The Royal Commission appointed to administer the surplus of £213,000 from this Exhibition showed wonderful foresight by purchasing a large piece of land in Kensington Gore. This fact is mentioned because it is often not realised to-day how much scientific, technical, and art education have benefited from the Exhibition of 1851. On the land so acquired, there now stand the South Kensington Museum, Schools of Science and Art, Natural

History Museum, Patent Museum, Indian Museum, Royal College of Music, Imperial Institute, Royal Albert Hall, Museum of Scientific Instruments, Central Technical College, Royal School of Art Needlework, Museum of Fish Culture, Anthropological Laboratory, School of Art Woodcarving, School of Cookery, and Home Arts and Industries Association. In addition, many science scholarships have been provided. The relatively small surplus of 1851 has become a national asset, now valued, it is believed, at something like two millions sterling.

The Great Exhibition of 1862 was visited by 6,200,103 persons, and other Exhibitions held at South Kensington in the early 'eighties were remarkably successful. Thus the "Fisheries," in 1883, was visited by 2,703,051 persons; the "Healtheries," in 1884, was seen by 4,153,390 visitors; and the "Colonies," the Colonial Exhibition of 1886, attracted no fewer than 5,550,745 visitors. Very successful also was the Glasgow International Exhibition of 1901, which drew an attendance of 11,497,220

The British Empire Exhibition was open for six months in 1924, and was visited by 17,403,119 persons, the highest attendance on one day—Whit Monday—being 321,232; but it had to face almost continuously wet weather. The accounts for 1924 show a heavy loss—about £1,800,000, but it is hoped that the present year's exhibition, 1925, will be favoured with fine weather and prove a great success. The enormous amount of hard work and energy expended by those promoting and managing the affairs of the Exhibition, well deserve an adequate reward, which it is hoped the British public and visitors from abroad will see fit to give this year.

It must be remembered, however, that in any case this Exhibition has had effects far beyond the immediate interest of those who have visited it. It has promoted commerce and good feeling throughout the Empire, and has drawn many thousands of visitors from overseas to this country.

With the kind assistance of Sir Lawrence Weaver, K.B.E., F.S.A., Director of the United Kingdom Exhibits in the Art Section, on the Board of the British Empire Exhibition, the author has been able to obtain particulars of the various individual Conferences and Congresses held at Wembley, in 1924, representing a total of no less than one hundred. In the aggregate about five hundred meetings took place in the four

halls and two committee rooms devoted to the purpose. About one-third of these totals represented the activities of scientific and technical institutions, societies, and associations.

The following are some of the names of the technical organisations which held Congresses at the Exhibition :—

METALLURGICAL.

Iron and Steel Institute.
Institution of Mining and Metallurgy.
Institution of Mining Engineers.
Institute of Metals.
National Federation of Iron and Steel Manufacturers.
Mining Association of Great Britain.

MECHANICAL.

British Engineers Association.
Society of Engineers.
Institution of Locomotive Engineers.
Institution of Automobile Engineers.

ELECTRICAL.

British Electrical Development Association.
National Society of Supervising Electricians.
British Electrical and Allied Manufacturers Association.
Incorporated Municipal Electrical Association.
District Joint Board of Employers and Staff of Electricity Supply Industries.

GAS.

British Empire Gas Committee.
British Commercial Gas Association.

GENERAL.

World Power Conference.
British Science Guild.
Ceramic Society.
Faraday Society.
Illuminating Engineers Society.
Institute of Transport.
Institution of Petroleum Technologists.
Institution of Municipal and County Engineers.
Institution of Sanitary Engineers.
Town Planning Institute.

In addition, there were many Congresses dealing with education, commerce, economics, and other subjects of general interest and importance. All this mental activity must surely have contributed materially to the spread of education and the progress of the world.

It is not possible to state the number of papers read at all these conferences, but at the World Power Conference alone nearly 400 papers were presented, and many of them were read and discussed. Speaking of the meetings of scientific and technical societies, that of the Empire Mining and Metallurgical Congress, before which many papers on ferrous and non-ferrous metallurgy were presented, in addition to those on mining, petroleum, and general subjects, also proved a most valuable one. A special medal struck to commemorate the holding of the first Empire Mining and Metallurgical Congress bears a reproduction of the Arms granted in 1568 by Queen Elizabeth to the Society of the Mines Royal, with an inscription on the reverse.

Whilst it is invidious to mention names, great credit is due to Mr. D. N. Dunlop, who organised the remarkable Congress known as the World Power Conference, of which he was the Director.

In the same way the best thanks of this country were due to the late Viscount Long, of Wraxall, for the admirable way in which he presided over the Empire Mining and Metallurgical Congress, which was held in June, 1924, and to the General Secretaries, Messrs. C. McDermid and G. C. Lloyd, and the Deputy General Secretaries, Commander R. E. Stokes-Rees, R.N., and Mr. G. Shaw Scott.

It may be interesting to add that the Palace of Engineering alone covered about five acres, and the rent paid for floor space by the 405 firms exhibiting in this building was no less than £150,000. The exhibits on view were remarkable alike by their number, variety, and excellence, and it was evident on a little reflection that the metallurgist had played an essential part in the production of each.

There is no doubt that the firms concerned in engineering and metallurgy would have retained their exhibits for 1925 but for the very severe industrial depression this year, 1925, necessitating the cutting down of all possible expenditure.

International Co-operation.—During a period of nearly forty-five years, it has given the author great pleasure and satisfaction, not only to carry out his own research work, but also to be able to help numerous scientific and technical investigations with advice and assistance. It has also been a pleasure to furnish many thousands of specimens of various alloys of iron and steel to investigators all over the world to enable them to carry out research and experimental work.

The list of names, in Appendix IV, of those with whom the author has been in more or less direct co-operation during the long period mentioned, is a striking testimony to the international character of scientific work. With all these workers—and the list is not complete—the author has been in touch personally or by correspondence, and in many instances he has supplied them with specimens of steels for the furtherance of research. Add to this imposing list the names of those with whom each of these workers has co-operated, and the true significance and extent of international relations in science become increasingly apparent. In this "snowball" effect or, to change the metaphor, in these ever-widening ripples, lies the secret of the phenomenally rapid progress of scientific knowledge during the last fifty years. Sometimes, but less often than might be supposed, a master discovery or invention is made which is destined to become the origin or centre of a whole system of advances; but, whether a discovery prove to be fundamental in nature or merely a "ripple," it is important to remember that it ought to lead to further results. The best means of effecting this steady advance is by correlation of individual researches, and by co-operation not merely within the boundaries of one country, but, so far as possible, internationally.

One phase of international co-operation in scientific matters was exemplified, in a manner most gratifying to the author personally, by the visit of the Deputation from the Engineering Societies of the United States in 1921. This deputation came to London in connection with the presentation to the author of the John Fritz Medal. Amongst its members was Mr. Ambrose Swasey, who has given many hundreds of thousands of dollars for research in America. His great work in establishing the Engineering Foundation Board has already been mentioned in Chapter XV.

Judging from the many letters of thanks received from those at home and abroad, the Address which the author delivered to the above-mentioned Deputation, in appreciation of the honour conferred, did, as was hoped, help to cement the good feeling between engineers of all kinds and classes of the Anglo-Saxon speaking races.

International co-operation in another direction—the fruitful policy of encouraging research—is exemplified by the munificence of Andrew Carnegie in founding libraries, scholarships, and other educational facilities; also, by the participation

of foreign countries in the Ramsay Memorial Fund. Substantial subscriptions to the fund have been made, and in most cases Ramsay Fellowships tenable in any University of the United Kingdom have been founded, by America, Chile, Denmark, France, Greece, Holland, India, Italy, Japan, Norway, Spain, Sweden and Switzerland.

The value and possibilities of such international movements can hardly be exaggerated. One of the author's friends, a young Frenchman who is likely to become one of the important scientists on the Continent, came to work in London under the provisions of a Ramsay Fellowship. He was in this country for a couple of years and after his return he wrote as follows, referring to a certain passage in one of the author's addresses:

> "With reference to your remarks on international co-operation, to my mind its relative importance should be multiplied many times over. After the time I have spent in England, where I was received in such a friendly manner, I feel myself related to many British people as closely as to my best friends in France. I do not see why we should make a difference in our speeches between people we praise equally in our thoughts. This would hasten and spread mutual esteem, and gradually, step by step, mutual understanding and co-operation. This co-operation will be absolutely necessary for the realisation of the big tasks we all have before us."

This letter proves, if proof be needed, that the international co-operation in subscribing to the Ramsay Memorial Fellowship Fund will have far-reaching effects, not only in diffusing knowledge, but also in promoting international good-will.

A National Science Day.—In the course of an Address upon the History of Mechanical Engineering, delivered to the Women's Engineering Conference in 1923, Professor F. W. Burstall, M.A., Dean of the Faculty of Science at Birmingham University, asked:

"What of the future?" What is going to be the result of all this present enormous development by civil, mechanical, electrical, metallurgical and chemical engineers? He pointed out that if we are careful in learning how to handle the immense powers of nature put at our disposal, with thought for others, then the world will be greatly benefited; but if we are selfish, then, like Rome, we shall destroy ourselves. In this respect, therefore, the factor of comfort and progress must be that of the mean value, that is, for the average man. If we get ahead of the average man, he will not have our rulings. Therefore we should try to pull him up to our level, not push him down. With this the author is heartily in agreement.

An effective method of bringing home to the " man in the street " the great importance of science in all our affairs would be the establishment of an annual Science Day. Such a proposal was put forward in France a few years ago. Asked with regard to the suggestion, the author's friend, Professor Henri le Chatelier, said, and rightly so, that what was chiefly required to advance science was serious workers having the sacred fire in their hearts.

An annual Science Day would demonstrate to all classes the extent and value of this branch of human knowledge. As a consequence, it would increase the esteem in which scientific workers are held, and raise the status of science and scientists.

The author's suggestion, briefly, is that a Science Day might be arranged in which the Universities of the nation, including of course Oxford and Cambridge, should be asked to co-operate; also the various Applied Science Departments; Colleges; Schools, public and private; Museums; Public Libraries; Scientific and Technical Institutions; and other bodies.

In such an attempt it would be most desirable to enlist the sympathies of the Labour Party, as their journals, even of the most extreme kind, would surely lend a helping hand. In fact one of the main objects of celebrating such a Day would be to interest Labour and its representatives.

With the celebrations might be included references to eminent British Scientists of the past, showing what a large part they have played in the world's progress. To some this suggestion may sound impracticable, but the author feels sure that a celebration of this nature will ultimately materialise.

In this, as in all other matters, action by the community and a successful issue depend primarily upon individual effort.

Conclusion.—In conclusion, may the author say to the younger men—some of whom may, during their career, be cast down by apparent want of success—do not be disheartened or discouraged; renew your efforts; try again. This is specially applicable to those engaged on research work which includes and leads to discoveries and inventions. It must not be forgotten that the great achievements of the human mind, and effort in new directions, are at first generally received with distrust. The author can speak on this matter from the experience obtained in developing his own inventions. Perseverance in the highest degree is required to achieve success.

Except in the few cases which can almost be counted on the

fingers of one hand, success can only be attained by years of hard work and painful toil. Nevertheless, as Shakespeare has well said:

> "Men at some time are masters of their fates;
> The fault, dear Brutus, is not in our stars,
> But in ourselves, that we are underlings."

Also, the beautiful and noble words of Milton on education, presented in the foreword of this book, deserve to be read and taken to heart. They were written by one of our greatest Englishmen, who himself must have struggled against the many difficulties, some of them apparently insuperable, to which he was condemned by his blindness. He toiled hard and long against many obstacles in his path; nevertheless, how wonderfully he overcame them and achieved that great position which is so deservedly his in the Anglo-Saxon Roll of Honour.

We may not all reach the greatest heights. Every soldier in the trenches was not a General. Nevertheless, it was the ordinary soldier—rank and file—who, by doing his duty, enabled the war to be won. Therefore let it be remembered that those of us occupying even the humblest position in life can still, by doing our duty, help on our day and generation.

A short time ago, whilst paying a visit to the ancestral home of Lord Chichester at Lewes, near Brighton, the author came across a remarkable proverb which may here be mentioned. Lady Chichester was showing some of the interesting family heirlooms. Amongst them was a Prayer Book dated 1646, and used by Oliver Cromwell—in fact, in it his initials were written by himself. On one of the opening pages were the following words "*Qui cessat esse melior cessat esse bonus.*" A free translation of this might be rendered as—"He who ceases to aim at better things will cease to do good things." Indeed a fine motto for all of us to contemplate and ponder over, whether individually or nationally. Let the spirit of these words be the aim of all of us, then there need be no fears for our position in the great unknown future, difficult as this may now seem.

APPENDICES.

APPENDIX I

INTRODUCTION.

The author of this remarkable Latin poem "FERRUM" was the Reverend Father Gilles Anne Xavier de la Sante, a Member of the Society of Jesus, who was born at Redon in 1684, though others say either at Vennes or Rennes. Whilst few details of his career are forthcoming, it is stated in the *Biographie Universelle*, published in Paris, Furne, 1833, Vol. 5, that he filled with considerable success the Chair of Rhetoric at the College of Louis-le-Grand. I am much indebted to the Abbé Delepine, Dean of Lille Cathedral, for the following further particulars. Father de la Sante became a novice in the Jesuit Order when only eighteen years of age. In later life he occupied the Chair of Humanities at Caen University. He died at Paris in 1762.

The late Professor Floris Osmond, who did so much for the Science of Metallurgy, translated the poem into French, taking as his basis an edition printed in 1809 which, in his Introduction, he states was carefully compared with the 6th edition published in 1732. The poem was first written about the year 1707, and was published in the series *Musæ Rhetorices*. The work is commended by Grignon, and an earlier translation into French is extant, by Monsignor de Montfleury, Canon of Bayeux Cathedral. Osmond, in his Introduction praises it as being both "eloquent and spiritual." He playfully suggests that the poem contains internal evidence that the author was an allotropist, and that this was one of the inducements which led him to succumb to the temptation of translating the poem into French.

The present translation in its English form has been carefully collated with the original Latin, to which it adheres more closely in many passages than the French translation by Osmond.

In a copy which he presented to me, Osmond has written "Herein, dear Sir Robert, you will find an ancient form of the allotropic theory, with which it is possible you are not acquainted. It is perhaps more attractive than my own. I hope you will find it to your taste, and remain, yours most sincerely, F. OSMOND."

Whilst Osmond's edition is accompanied by several pages of Notes, it has not been thought necessary to reproduce these in their entirety, as they frequently refer to phrases which occur in French poems of the 17th and 18th centuries, and do not really bear on the poem itself. In order to elucidate certain passages some fresh notes have been compiled. These have been initialled respectively "T" and "O," "T" standing for the translator, and "O" indicating that the note is based upon one written by Osmond himself.

This poem on the important subject of iron, contributed nearly two hundred years ago by the Reverend Father Xavier de la Sante, whose erudition on metallurgical matters enabled him to weave into it such interesting facts and fancies in the clever manner he has done, is indeed a wonderful piece of work, specially bearing in mind that metallurgical knowledge was then (1735), meagre and scanty, in fact much of the lore of that day was merely what we should now term quackery. But for want of space, some curious examples of the extraordinary suggestions put forward for serious consideration for the working and treatment of iron could be instanced. There is, however, no taint of the kind present in this poem.

The extraction of the ore, its smelting and production in the form of Pig Iron, and finally "STEEL," the most useful of all metals, are dealt with in a most interesting manner. The thousand and one purposes for which iron is utilised show that not only is it of the highest importance but that it is entitled to be truly termed a noble metal, much more so than gold, for it is upon iron that modern civilisation chiefly depends for its existence, more than any other. The poem concludes with the beautiful allegory of Sidère and Sidérite, which exemplifies in classic terms the attraction of the loadstone for iron.

The frontispiece of this book shows a bronze group embodying these poetical ideas so well expressed by Father Xavier de la Sante. The execution of this work of art for me

was carried out by Mr. Frederick J. Halnon, R.B.S., the group being exhibited at the Royal Academy in 1923.

As a slight appreciation of the many kindnesses I have received over a long period of time from numerous French scientists, metallurgists and engineers, it has given me much pleasure to present a replica in bronze of this group to the Conservatoire des Arts et Métiers, Paris, where my friend Dr. Léon Guillet, Member of the Académie des Sciences, is now Professor of Metallurgy.

My readers will therefore understand why I have been so much interested and studied so closely the translation of this poem in the little book presented to me in 1906 by my friend Osmond. Also why, as a metallurgist, I felt that Metallurgy had indeed earned not only a place in Science but in the Arts and in Literature, as exemplified in the poem written by this learned Frenchman now passed away so long ago. The marginal titles added to the poem represent an excellent history of the state of the science of metallurgy in France in the eighteenth century.

I should like to take this opportunity of expressing my heartiest thanks to Mr. L. P. Sidney for the careful and painstaking manner in which he has not only translated this poem for me, but has also arranged and presented it in our language in most excellent poetic form.

R. A. HADFIELD.

July, 1925.

FERRUM.

THE POET'S INVOCATION.

Now that, upon the broad Hungarian plain
The Turk, in panic, Eugène,[1] counts his slain,
Where sons of Gaul sustain her former foe,
Brothers in arms, who once laid Austria low,
The while proud Sultans bend before thy sword
I sing of IRON ; of its secret hoard
How to extract, and how its ores to smelt,
The varied uses which our arts have lent,
And Thou, O Phœbus ! thine assistance render,
That though my theme be hard, my script be tender.
Thou too, who first, in far Sicilia's field
The Smith his hammer taught to poise and wield,
Thou, Vulcan ! too, I hail ! Aid my endeavour
Unbar Chalybia's guarded gates, that ever
Thy footsteps guiding, I may thread its ways
Where nought but sullen fires shed ominous rays,
While Etna' flanks re-echo with the sound
Of anvil's clash and hammers' dull rebound !

PASSING OF THE GOLDEN AGE.

Ere Jupiter ruled o'er a once happy Earth,
None knew the dire secret that sprang with thy birth ;
The Golden Age flourished ; Mankind knew not how
For impious battle to strengthen his blow.
Yet Nature, the Parent of Life and Desire,
On Destiny's pages saw written in fire,
The age that must be, when mad fury should reign,
And the sword should be quenched in the blood of the slain.
The All-loving Mother, in anguish and terror,
Sought but to postpone, for avoidance were error,
And stealthily hid the foul metal from sight.
In the depths of the earth and the darkness of night,
She buried it, hoping the secret would last.
Alas, it was fruitless ; the Golden Age passed !

And now, what hapless times that earth attains,
Where, like a pestilence, foul violence reigns,

When of the hidden metal's horrid lure
The IRON AGE is born, still to endure!

THE ORES: HOW LOCATED.

Now, thou who would'st, by thy forefathers' lore
Locate the mine, its hidden wealth explore,
Heed thou the precepts of my tuneful Muse,
Employ its treasure, but—do not abuse!
Not every site repays thy painful toil,
Nor rich load scatter wide 'neath every soil.
And, for thy guidance, hidden veins to trace
Thou need'st must scan earth's features for a space.
If, 'neath thine eyes the clay doth ruddier show,
And harder, more compact and denser grow,
There lies the ore! A stronger proof will be
When on a rain-swept surface thou shalt see
'Midst sand and pebbles—water borne—alone
The heavy rounded lumps of iron stone!
'Tis this that, to thy purpose apt, will yield
The metal latent in the fruitful field,
Nor doubt but that at last, by fire's ordeal
Amongst its ashes thou shalt find the STEEL!

THE ORES: HOW EXTRACTED.

Without delay, forthwith assemble round
The stalwart labourers who till the ground,
Deep-chested, brawny-armed; their tools provide
To open up the quarry, far and wide;
The pick axe, shovel, heavy-pointed stake,
To dig the trench, the heavy ore to break;
And while, beneath their blows, the trembling soil
Gives up its treasure, be it others' toil
To free the ore from dross, in piles to stack,
That others yet may bear on bended back,
With aching sinews and with laboured sighs
Across the plain, to where the river lies.
Now to erect, athwart the open mine,
A windlass, and a winding rope entwine
Around a drum, deep grooved to take the chain,
And raise the heavy ore; a kind of crane.
Then, to two wicker baskets fix the ends
That while one rises, loaded, one descends
And then, revolving in the other way,
Raises another to the light of day.

The endless coil, thus moving, brings the ore
To surface and returns again for more,
Nor must thy labour pause, until the vein
Exhausted, yields but earth and dross again !

WASHING AND SCREENING.

And now, before mine eyes, exposed to view,
A monstrous chasm yawns, where men, anew,
With frantic labour pierce the gloomy sides
And tunnel 'neath the clay, in seething tides.
Some cleave deep channels through the massive vein,
Some shore the roof, while others yet again
In darksome caverns hew the ore, which gleams
Dull, in the oil-lamps' ineffectual beams.
See now, upon the open ground above
The patient mules await the treasure trove
In harnessed train, that, to the river near,
Their ever-growing load of ore may bear.
A chain of dams, with floodgates that provide
Means to direct and to control the tide,
Flushes in flowing streams the dross and clay
Which, from the hollow pans, are borne away,
Leaving upon the screens the denser earth
Fit for its purpose in the furnace hearth.

VULCAN: HIS FIRST FORGE.

O Muse, come tell me how the blazing fire
Can separate the metal from the mire ?
And who, of all the gods, was first to pour
The liquid iron from its stony ore ?
When Vulcan, by his Father's foot[2] propelled
Unfatherly, and from high Heaven expelled
To Earth was hurled, so heavy was his fall
He met the fate of simple mortals all.
His thighbone broken, both his pain and pride
He sought, in Etna's fastnesses, to hide,
And like a mortal, hid from mortal's ken
Nor deigned the tasks that fall to mortal men.
'Twas thus he found the ore, and having found,
For means to smelt it straightway looked around ;
Within the cavern's cleft a forge was raised
An ox-hide bellows urged the fires that blazed :
A thousand schemes his busy brain supplied
Nor could his strenuous purpose be denied.

Boreas and the Cyclops Attend Birth of Iron.

The deep Sicilian Grottos of that day
Sheltered the home where old Boreas lay,
And with his windy blasts, the trembling soil
Revealed the ardour of his barren toil.
This Vulcan saw, and while Boreas slept
The god, from his concealment, softly crept
And having bound him tightly as he lay,
By fear of death compelled him to obey.
Now Boreas' breath the bellows supersedes,
The fire has all the current that it needs,
Though first he sought, by mighty gusts to drown
The flickering flame, that ever fiercer grown
Blazed hotter still, the while he lay confined
Condemned to furnish forth fresh blasts of wind,
And, ever labouring, find, alas too late,
Himself the sad accomplice of his fate!
Around him, frantic, swarms the Cyclops band
And hurl fresh burdens on the blazing strand:
The ore and charcoal, its insensate greed
Devours; from the elements proceed
Volumes of smoke and sudden glints of fire
While glowing ashes scatter o'er the pyre:
The seething mass, to yield at length constrained
Gives up the iron that its pores contained.
Earth trembles, and the rocky walls around
Are hurled asunder, with a hollow sound
The fires of Etna, belching to the skies
Proclaim the birth of IRON! All that lies
Portentous, in that birth, shall MAN acclaim
To use, adapt, and shape to human aim.
Learn of that god himself; let Vulcan teach
And emulate the early workers each,
Brontes, Steropes, all the Cyclops clan [3]
However skilled shall be out-matched by Man!

The Furnace: How Constructed.

With patient art a favoured spot select,
Its contours scan, its boundaries erect;
That site is best with water well supplied
To serve thy need in ever-flowing tide,
And forests vast, whose sylvan boughs supply
The fires that shall be lighted, by and by.
Then, on an arched foundation, in that space
The outlines of thy future furnace [4] trace.

A hollow pyramid must next be made
Where both the ore and charcoal may be laid;
Its apex earthward, that its sloping sides
May form a hearth to catch the molten tides.
Then, four-square, on the base the walls erect
The front one buttressed, better to protect
The workers, and a roofed-in porch prepare
That other workers may seek shelter there;
Lastly supply the furnace lining, and
Consolidate the whole with clay and sand
To bind the joints, so that, when they dry
Compact, the stalwart walls the fires defy!
In order, more and more to safety cleave,
A solid binding round the furnace weave
With bolted ties of timber armoured true
Lest the fierce fires should burn the furnace through.

Dessand's Furnace in Nevers.

But stay! What need of halting rhymes to show
What plain examples boot us best to know?
Then follow swiftly, while I lead the way
To where such rules were given amplest sway.
Close to Montigny such a furnace stands
As though it came from Vulcan's very hands.
Its lines so apt, its purpose so conceived
That Cyclops built it well might be believed!
As though, an exile from his mountain bare
He sought anew both home and labour there.
This furnace, near Nevers, by Dessand planned,
Lies in a pleasant valley—all the land
With sylvan groves surrounded, yields the store
Of fuel [5] needed for the iron ore.
The river, winding out from lake to lake
By cunning art, its share is made to take;
The rapid stream the mill wheel's need provides
And turns to power its fast-flowing tides.

The First Cannon Ball Forged.

Another spot there is, of equal fame
In Berry, Ardent is its well known name.
What name more apt? Its ardent fires recall
Where first great Condé forged his cannon ball,
Which in its flight spread havoc and dismay,
And swept the foeman's crumbling walls away.

Happy event, and happier still that land
That lent such weapons to such victor's hand!
The Mars of France, in god-like combat rose
And vain thine efforts, Europe, to oppose!
Though leagued against him, tireless Victory arms
His cause, and crowns the victor with her palms.
Fleming and Spaniard, and the Teuton horde
In vain withstand the onslaught of that sword;
Their life-blood mingles in the Meuse, the Rhine
Whose flowing streams are reddened with that wine,
While Roycroy, Lens and trembling Senef hear
The cannon's roar, resounding far and near.

THE AIR BLAST.

But stay, my gentle muse, 'tis not for Thee
To dwell on battle horrors, nor for me
To sing great Condé's praise. Can I endow
More fame, or wreath fresh laurels for that brow?
So, to resume. Our task, unfinished yet
Requires a pair of bellows, firmly set
The air, imprisoned in their heaving flanks
Escapes from twyers in the furnace banks
To urge its fires. It constitutes the soul
Of flame; its very maintenance the goal
Of ceaseless labour. To assist thee, bring
By timbered channels, water from the spring
To turn the water wheel and drive the shaft
Which works the bellows and sustains their draught;
Thus, as the jets ensue, and constant flow
Hotter and hotter still the fires shall glow.

THE CHARGE: TAPPING THE FURNACE.

A working furnace, like an ogre, feeds
Therefore have ready all its hunger needs.
A host of servitors before it pour
From ample stocks the fuel and the ore.
Nor is this all: a flux too thou must add
Which often near the ore beds can be had;
A white and porous stone, whose nature lends
Assistance to the burden which it blends.
At lower temperatures such mixtures melt[6]
'Tis easier thus, the rugged ore to smelt,
The penetrating flux its bonds oppose
In vain; it yields and softens, melts and flows;

The fire its particles asunder smites
The flux those particles again unites !
Yet do not take too much, and from thy store
Add just enough. It will suffice. No more !
'Tis thus that iron liquefies, although
Inert and sluggish yet its viscous flow.
The flames belch forth, the lurid sparks now fly
And dense black clouds of smoke obscure the sky !
The dross, reduced by action of the fire,
Floats as a slag upon its burning pyre.
By this the master of the forge can tell
The moment ripe, if all be going well,
To summon to his aid his swarthy band
Of fellow workers, each to bear a hand ;
Assigns to each his task ; they rally all
Like warriors at the sound of trumpet call.
Their horrid cohorts round the furnace form,
Like Furies, from Tartarean caves they swarm
Haggard and blackened. 'Neath dark shaggy brows
Gleam piercing eyes, that the fierce fire endows
With lurid light ; their shrunken shapes betray
The tribute to their task they daily pay.
Their dried-up skin, their wretched, wasted frames
The prey of arduous toil and scorching flames.
They seem to be of some foul, monstrous birth
Condemned awhile to labour thus on Earth !
Warned by their leader, one will first prepare
His special task, to draw the slag with care,
The others answer to their leader's call
Thrilled at the summons, eager, one and all ;
And when the slag floats on its fiery lake
Another, in the wall, now drives a stake :
The bubbling slag, tumultuous, in a rush
Of molten streams, escapes, and with a gush
Pours forth, with reeking fumes of sulph'rous smoke
And tongues of flame, as if all Hell had broke
Its bounds ! Nor is the dread task ended : Sand
Is needed to repair the furnace, and
Its gaping wounds with water be supplied,
Nor in that combat can it be denied
That other wounds are dealt : Each shaggy mane
Proclaims the triumph of the scorching flame ;
The lungs, oppressed with laboured cough, the smell
Of smould'ring clothes ; the blistered hands, as well.
Meanwhile the slag-stream ever darker grows

And ever cooling, now more sluggish flows,
While, purified, upon the furnace hearth
Lies the dense iron, freed from Mother-Earth!

Casting and Refining.

A narrow channel in the sand now trace
To guide the metal to its casting place.
The tap hole, in the hearth, made fast with clay
Must next be opened. To the light of day
Now flames the molten metal, flowing red,
A glowing stream, towards its sandy bed:
The sloping sides its torrents now enfold
The iron shapes itself, within its mould,
Sets and contracts, and ever quieter lies,
Grows cooler, hardens and solidifies.
When cold, remove it. From the mould we dig
The heavy mass of what is known as "PIG"! *
A further care must now engage the mind;
The pig, indeed, has next to be refined.
Reheated to bright redness, once again,
And then upon an anvil duly lain.
Beneath the hammer denser forms [7] it takes,
And, as the blacksmith chooses, so he makes!
Thus will art aid what nature first hath wrought
And iron is to due perfection brought.

Thus far my Muse, in halting verse displays
The mode of making iron. Of the ways
In which 'tis used be now my task to sing,
And ancient lore fresh inspirations bring.

Gifts to the Gods bestowed on Mortals.

When from Olympus high, in happy mirth,
The gods themselves descended to the Earth,
And on the grassy slopes of Etna spread
The feast to Vulcan, and his marriage bed,
Both Hymen and the Queen of Love were there
And nectar flowed in many a goblet rare.
The god, inspired thereby, to show his love
His skill in metal working sought to prove,
His leathern apron donned, his hammer seized,
And grasped his tongs. His audience, greatly pleased

**Porca*, and therefore, more correctly the *Sow*. Vergil, however, employs the word *porca* to describe the male of swine as well. (T).

Watched with amaze the dextrous strokes which
wrought
A thousand varied forms. The lesson taught
They craved as gifts fresh tokens of his skill
And Jove himself proclaimed his royal will
That iron for his future bolts be poured
While Mars besought a helmet and a sword;
Athene begs a breastplate and a shield,
Cupid, new arrow tips with which to wield.
Weapons more potent yet than those he wings
To harass mortals with their deadly stings.
Now Neptune seeks a Trident; Ceres fair
What shall the god now give thee, as thy share?
Ceres, for peaceful uses, begs a plough:
Fortuna deems a coffer were enough
To guard her treasure from a jealous eye;
And—thus equipped—the gods return on high
And there decide, on mortals down below
Their new-found treasures forthwith to bestow!

The War God arms his warriors for the fray
And Ceres next her ploughshare gives away,
While frowning Fortune, for the miser's gold
Confers her coffer, triply-locked, to hold.
With these new uses, newer needs arrive
And Industry, to meet those needs, will thrive.
No useful art, but iron still supplies,
A thousand uses, from its use, arise!
Without it, barren lies the unploughed field
Nor to the husbandman, the harvest yield,
Nor precious cargoes, borne before the breeze
Sail the twin spheres and cross the Indian Seas
Bearing the merchants' stocks, that o'er the main,
Now changed to gold return to them again.
Ye, who would shun the perils of the deep,
The safer paths of metallurgy keep;
Build forge and furnace in thy native land,
Transmute to gold the iron safe at hand!

The Uses of Iron in War.

Although of honest Industry I sing,
My inattentive Muse again takes wing.
Where am I now? and whither through the air
Doth Pegasus his willing victim bear?

He flies to far Belgrade. Those rampart walls
With trembling heart I view. Their sight recalls
The by-gone horrors of more ancient times
When Christian martyrs died in distant climes
Chained to the stake, of cruelty the prey,
Yet victors—in the name of Christ—that day!
O grant that ever, in Thy name, O Lord
Thy worshippers thus triumph o'er the sword.
The hurtling shell, the flashing blade, the spear
Now iron fashions, in the flames of fear
Fresh conflicts rage, and fiery masses fly
With trails of smoke athwart the gleaming sky;
The cannon's roar the trembling rampart walls
Re-echo, and the crumbling bastion falls;
The roofless dwellings, stricken, fill the gap
The shells, the citadel's foundations sap;
Death stalks abroad, beneath his victims, slain,
Earth reddens, and the living flee—in vain!
Here must I pause; my Muse would here impart
How, in that havoc, IRON plays its part.
A thousand dead lie, stricken by its aid.
The rigid mortar, of CAST IRON made
When through the touchhole, by the lighted brands
Its charge of nitre suddenly expands
Belching the hollow balls, that with their breath
Of burning sulphur swiftly deal out death!
They whistle through the air, and with dull sound,
Like thunder, burst, to scatter all around
The ragged fragments that their spheres contain
Naught can their path impede, their progress stay—
Men, trenches, walls, alike are swept away.
No fortress built, no dwelling, and no town
But fire, by IRON aided, brings it down!
Eugène, ubiquitous, in those dread days
Again hath doubly won the victor's bays;
A thousand laurels grace thy manly brow [8]
Who spread that terror. See Byzantium now
With sickening fear, thy nearer progress mark
The while her pallid crescent-moon grown dark.
'Tis thus that IRON, when to ARMS allied
Bears victory and triumph in its tide!

PHILOSOPHERS SEEK TO EXPLAIN MAGNETISM.

Now to resume, and IRON be my theme
The War God's image fades, as in a dream.

By other aims the metal is possessed
The magnet's lure attracts it, thus obsessed
To its dear loadstone, like a lover flies
The heavy metal, and thus woo'd, defies
Restraints of mass, nor intervening space
Can hold it from the magnet's fond embrace.
Of old the learned doctors sought the cause
Of this attraction, and to learn its laws
And modern science too, still strives to learn
What makes the iron to the magnet turn ;
Thus, to this day the learned strive in vain,
In hostile camps divided, to explain
The nature of that force, which will outlive
All far-fetched explanations they can give !
One school, by vortex-motion in a rare
And subtle medium, claims it can lay bare
The facts. That medium fills, they say, the space
Between the particles ; its rapid race
Imparts like motions in the space inside
The iron mass ; this ever flowing tide
The molecules of air within expels
And their reaction on the mass propels
The one against the other. Others find
There is, of matter, a magnetic kind
Which like a snail, can worm its spiral way
Within the spaces of the metal. They
Provide a thousand channels for its flow
And thus, from pole to pole, 'twill swiftly go
Forming at last a closed circuit where
The loadstone particles await it there.[9]
These particles have hooks. It is their view
That to these hooks is magnetism due !
They grant that in this process air may play
A part, to help the fluid on its way.
This theory wild, old Epicurus told
That atoms, by their hooks, together hold,
And Gassendi,[10] this theory once again,
(As though those atom hooks had hooked his brain),
Hapless philosopher, this madness sings
Bound tight to Epicurus' aprong strings,
Minerva would have shamed such vain conceits
'Tis true the Sophists claim a thousand feats
Their work transmutes base metals into gold
And the Elixir seeks, so we are told !
Believe who can, such gold is really pure

Or that forever men can life endure,
The love of iron for the magnet springs
From other causes than the poet sings!

LEGEND OF SIDÉRITE AND SIDÈRO.

In vast Magnesia, in the days of old
There dwelt two brothers, shepherds we are told
Of equal worth and beauty. Sad the fate
My mournful verse with tears must now relate.
In character akin, of equal age,
Pious of mind, modest of mien, and sage,
The ties of blood that held them were no more
Than the dear love each to the other bore.
On neighbouring slopes their timid flocks they tend,
Nor dream their peaceful lives can ever end
In tragic destiny. One starry night
Alone was musing gentle Sidérite
—Absent awhile his brother Sidèro.[11]
(These were the youthful brothers' names, we know).
Beside a murmuring stream, upon the grass
He lay, and watched the constellations pass
In all their splendour, o'er the skies above.

SIDÉRITE ATTRACTS GODDESS OF POLAR STAR.

In the far horizon, the latest love
Of Jupiter, Lycaon's daughter fair [12]
In that far arc that spans the outer air
The god had set, in that wide sphere to trace
The course of Heaven, and the resting place
Of this world's axis, that we call the Pole;
Her pure ethereal gleam awakes the soul
That stirs within him. That one ray hath cast
Its magic net. Now in its fetters fast
He lies. The goddess views him, and her heart
Glows to the flames his heaving breast impart.
His roseate blush, his graceful form but fan
That love the goddess feels for mortal man!
Her icy soul with fond desire burns
Nor seeks to stifle. From her car she turns
Love lends her wings, that fluttering from above
Waft her to earth in safety—and her love!
Although a while she dons a frail disguise
And as a Nymph, appears before his eyes,
Shameless, her mission she at once proclaims,

Nor pauses, to dissimulate her aims.
He crimsons 'neath the goddess' amorous glance,
She finds those blushes but his charms enhance—
Then trembling finds his tongue " O goddess " cries
The youth " May mortal lift aspiring eyes
" To one whose marriage-bed high Jove did grace
" What peril would there be in such embrace ;
" And what attraction could a goddess find
" In the devotion of a simple hind ? "
" Nay such high honour would unseemly be
" My brother's love is love enough for me ! "
'Twas thus he spake. With wrath the goddess burns
And swift from love to hate her passion turns.
Her outraged love, her pride alike inspire
To call upon his head her vengeance dire.
" Doth thou " she cries " My godlike will frustrate
" And spurn my love ? Then this shall be thy fate
" Hardened 'gainst love's assault forever be
" As adamant, through all Eternity ! "

She transforms the two Brothers.

She waves her magic wand, fell instrument
Of godlike vengeance, for that purpose lent,
And with it smites him. Through his blood he feels
The poison, as toward his heart it steals
Its venomed course, and turns to very stone
His limbs. His stiffening lips emit a groan
" O Brother, aid me ere I die " he cries !
His brother to his succour vainly flies
Too late ! He finds unhappy Sidérite
Now wholly turned to the stone, Magnetite
Whence magnets take their name. A flaming wrath
Invades his spirit, and his words pour forth
In wild despair. " O Brother, is it thee
" I now behold ? What then will come of me !
" Bereft of half my soul, can I survive
" Thy transmutation ? Nay, I will not live
" Without thee. Let my lot be, then, as thine ! "
And cleaving to that stone, with love divine
He holds it close embraced, and prostrate lies
Then to the goddess lifts his haggard eyes.
" Insensate, Cruel, see " he cries, " I lie
" A willing victim. I prefer to die !
" Strike, as thou struckest him. What had *he* done ?
" Gather thy trophies, goddess, and—begone !

The goddess turns, her eyes with menace glare,
" Thou too " she cries " Another form shalt bear
" To IRON be thou changed." With heaving breast
He sinks beside his brother, there to rest!
Their supine forms, recumbent, still embrace
Though turned to stone, naught can their love efface;
Magnetic bonds, in Death's cold grip unite
Brother to brother, steel to magnetite!
    Despite his cruel fate, O ! strange to tell
Sidérite, still beneath the goddess' spell
Her fascination feels. The polar star
Still beckons to the mariner afar;
The compass still directs his vessel's track
The needle, quivering in its quest, turns back
And forward, ever seeking. It will set
To the North Star alone. But even yet
One force can draw it from the Star above,
IRON, the symbol of Fraternal Love !

THE POET CONCLUDES.

    These verses, playthings of my student years
Revised,[13] I offer, with an author's fears
Would they might please you. Of how IRON'S made
In halting rhymes, to tell you I've essayed,
If you approve of that which I have told
Why then, *my* " IRON " barter for—*your gold !*

FINIS.

NOTES

1.—Prince Eugène of Savoy (1663–1736). The campaign referred to was against the Turks, led by Kara Mustapha, and culminated in the victory of the allied forces at Zeuta on Sept. 11th, 1679. (T).

2.—Vulcan, the only legitimate son of Jupiter, was according to one version, literally *kicked* out of Olympus by his father, but, according to another version was banished by his mother, Juno. (T).

3.—Polyphemus was the best known of the Cyclops, who included Brontes and Steropes. They acted as Vulcan's assistants at the forge. (O).

4.—Osmond remarks that the lines following are perhaps the least satisfactory part of the poem. The description is difficult to follow without a drawing, and not very accurate. (O).

5.—According to Grignon (1807) the consumption of charcoal was not excessive, being 1470 kilogrammes per ton of iron at a furnace at Urville and only 1140 kilogrammes at Bayard at a furnace which was operating in 1770. (O).

6.—The theory underlying this statement should be noted. It was but natural to believe that the flux itself was relatively fusible as it does, as a matter of fact, lower the melting point of the slag. (O).

7.—Note here the view, which still survives, that forging makes the metal *denser*. (O).

8.—The original "*mille unica palmes palma parit*" involves a pun which may be rendered thus :—

"*a thousand palms thy single palm now bear*." (T).

9.—The second—somewhat elaborate—theory that follows is that of Descartes and in certain respects it is not altogether radically different to some of the modern theories now in vogue. (T).

10.—Pierre Gassendi (1592–1655), philosopher, scientist and mathematician. His *Syntagma philosophicum* deals with logic, physics and ethics, and he defends therein the Epicurean system. (T).

11.—Σιδηριτης=magnes (magnetite).
Σιδηρος=ferrum. (T).

12.—*Lycaon's daughter*, Calisto, or Callisto. She had a son (Arcas) by Jupiter, and was eventually placed, for her own protection, in the constellation of *Ursus major* (Ovid, Metam. ii., 381–530). (T).

13.—*Incudi reddere versus* (Tacitus) Literally "to put on the anvil again"=to recast, to revise. (T).

APPENDIX II

EARLY WORKERS IN SCIENTIFIC METALLURGY.

Aristotle (Greece), 384–322 B.C., philosopher, described the manufacture of Indian steel.

Theophrastus (Greece), 374–287 B.C., philosopher, wrote on iron ore.

Diodorus Siculus (Sicily), 60 B.C., geographer, described the smelting of Elba ore.

Plinius (Italy), 79–23 B.C., naturalist, showed that the properties of iron depend upon its treatment.

Rugerus Theophilus (Germany), monk, dealt with iron in his " Schedula diversarum Artium " (1050).

Leonardo da Vinci (Italy), 1452–1519, physicist, artist, etc., introduced blast for smelting iron.

Vanuccio Biringuccio (Italy), 1480–1539, dealt with iron in his " Pyrotechnia " (1540).

Georgius Agricola (Germany), 1490–1555, dealt with metallurgy of iron in his " De Re Metallica " (published 1556).

Paracelsus (Switzerland), 1493-1541, chemist, improved metallurgical methods, discussed the distinction between iron and steel.

Lazarus Ercker (Germany), wrote on assaying (1574).

Louis de Geer (Sweden), 1587–1652, introduced the Walloon furnace.

Dud Dudley (England), 1599–1684, first smelted iron with pit coal.

Johann Rudolf Glauber (Germany), 1604–1668, chemist, discovered several metallic chlorides.

Simon Sturtevant (England), dealt in his " Metallica " with the use of coal for smelting (1612).

John Rovenzon (England), dealt in his " Metallica " (1613) with the use of coal for smelting.

Sir John Pettus, Knight (England), 1613–1690, author of metallurgical works.

Andrew Yarranton (England), 1616–1684, introduced tin-plate manufacture.

The Hon. Robert Boyle (England), 1627–1691, chemist and physicist.

Sir Isaac Newton, Knight (England), 1643–1727, scientist.

René Antoine Ferchault Réaumur (France), 1683–1757, physicist, wrote on cementation and decarburization.

Emanuel Von Swedenborg (Sweden), 1688–1772, engineer and theologian, wrote on iron.

G. Brandt (Sweden), 1694–1768, discovered cobalt (1733).

Benjamin Huntsman (England), 1704–1776, manufacturer, first to melt steel.

Benjamin Franklin (United States), 1706–1790, statesman and scientist, inventor of the Franklin stove.

Johann Andreas Cramer (Germany), 1710–1777, author, wrote on metallurgy.

Abraham Darby (England), 1711–1763, used coke for smelting.

Sven Rinman (Sweden), 1720–1792, wrote on metallurgy of iron.

Axel Frederic Cronstedt (Sweden), 1722–1765, mineralogist, discovered nickel (1751).

Joseph Priestley (England), 1733–1804, chemist, discovered oxygen (1774).

Richard Kirwan (Ireland), 1733–1812, author, first English writer on mineralogy.

Torbern Olaf Bergman (Sweden), 1735–1784, chemist, founder of analytical chemistry, drew distinction and explained differences between pig-iron, wrought iron, and steel.

Henry Cort (England), 1740–1800, engineer, introduced puddling and the use of grooved rolls.

Karl Wilhelm Scheele (Sweden), 1742–1786, chemist, anticipated Priestley's discovery of oxygen; discovered manganese (1774), chlorine, barium, and molybdenum.

Martin Heinrich Klaproth (Germany), 1743–1817, chemist and mineralogist; discovered uranium (1789) and titanium (1794).

Antoine Laurent Lavoisier (France), 1743–1794, chemist, creator of modern chemistry.

Johann Gottleib Gahn (Sweden), 1745–1818, chemist, isolated phosphoric acid.

Claud Louis de Berthollet (France), 1748–1822, chemist, discovered composition of ammonia.

Fausto de Elhuyar (Spain), 1755–1832, chemist, first prepared metallic tungsten (1792).

William Reynolds (England), 1758–1803, patented (1799) the use of manganese oxide for steel manufacture.

John Dalton (England), 1766–1844, chemist, published table of atomic weights.

Jeremias Benjamin Richter (Germany), 1762–1807, chemist, invented alcoholometer.

Louis Nicolas Vauquelin (France), 1763–1829, chemist, discovered chromium (1797).

David Mushet (England), 1772–1847, metallurgist, author, discovered blackband ore.

Sir Humphrey Davy (England), 1778–1829, chemist, first isolated potassium and sodium.

Jons Jakob Berzelius (Sweden), 1779–1848, chemist; prepared pure iron ; discovered selenium, thorium, and cerium ; isolated silicon ; and introduced the theory of allotropy.

Pierre Berthier (France), 1782–1861, chemist, wrote on metallurgical analysis.

Robert Sterling (Scotland), 1790–1878, patented regenerative principle (1847).

Michael Faraday (England), 1791–1867, chemist and physicist, investigated the properties of iron and steel alloys.

James Beaumont Neilson (Scotland), 1792–1865, invented hot-blast (1828).

Friedrich Wohler (Germany), 1800–1882, chemist, isolated aluminium (1827).

APPENDIX III

CLASSIFIED LIST OF PAPERS

BY

SIR ROBERT A. HADFIELD, BT., F.R.S.

SUMMARY

Section

(1) Manganese steel.
(2) Alloys of iron with silicon, aluminium, chromium, nickel, tungsten, copper, cobalt, molybdenum, and other elements.
(3) Sound steel.
(3b) Steel making.
(4) Mechanical tests.
(5) Hardness and hardening.
(6) Electrical and magnetic properties.
(7) Production of magnetic alloys from non-magnetic materials.
(8) Corrosion of iron and steel.
(9) Effect of low temperatures upon iron, steel, and alloy steels.
(10) Metallography.
(11) Pyrometers.
(12) X-ray examination of iron, steel, and other materials.
(13) Early history of crucible steel.
(14) Ancient iron and steel.
(15) Fuel.
(16) Addresses, presidential.
(17) Addresses, other than presidential.
(18) Progress of metallurgy.
(19) Contributions to discussions.
(20) Education.
(21) General.

(1) MANGANESE STEEL

No.	*Title.*	*Where read or published.*	*Year.*
1	Manganese Steel	Institution of Civil Engineers	1888
2	Some Newly-discovered Properties of Alloys of Iron and Manganese	Institution of Civil Engineers	1888
3	Manganese Steel	Iron and Steel Institute	1888
9	Iron Alloys, with special reference to Manganese Steel	American Institute of Mining Engineers	1893
13	The results of Heat Treatment on Manganese Steel and their Bearing upon Carbon Steel	Iron and Steel Institute	1894
15	Steel and Iron Alloys	Institution of Civil Engineers	1897
24	Alloys of Iron, Manganese and Nickel	Institution of Civil Engineers	1903
26	Iron and Steel Alloys	*Iron and Steel Metallurgist and Metallographist*	1904
31	Seventh Report of the Alloys Research Committee on "The Properties of a series of Iron-Nickel-Manganese Carbon Alloys" *	Institution of Mechanical Engineers	1905
58	Heating and Cooling Curves of Manganese Steel	Iron and Steel Institute	1913
60	Research with regard to the Non-Magnetic and Magnetic Conditions of Manganese Steel *	American Institute of Mining Engineers	1914
61	Manganese Steel Rails	American Institute of Mining Engineers	1914
64	The Magnetic and Mechanical Properties of Manganese Steel *	Iron and Steel Institute	1914
99	A Contribution to the Study of the Magnetic Properties of Manganese, and of some special Manganese Steels *	Royal Society	1917
126	The Magnetic Mechanical Analysis of Manganese Steel *	Royal Society	1920
128	On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese*	Royal Society	1921

* Joint paper with others.

(1) MANGANESE STEEL—Contd.

No.	*Title.*	*Where read or published.*	*Year.*
129	On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese*	Physical Laboratory of the University of Leiden	1921
138	Modern Trackwork and Its Importance	Institute of Transport	1923
140	Discovery of Manganese Steel and its Imporance to Modern Engineering	Brit. Sc. Guild	1923
145	Manganese Steel	Glazebrook Dictionary of Physics	1923

(2) ALLOYS OF IRON AND STEEL
(Other than Manganese)

No.	*Title.*	*Where read or published.*	*Year.*
4	Alloys of Iron and Silicon	Iron and Steel Institute	1889
5	Alloys of Iron and Silicon	British Association	1889
6	Alloys of Iron and Aluminium	Iron and Steel Institute	1890
7	Alloys of Iron and Chromium	Iron and Steel Institute	1892
9	Iron Alloys, with special reference to Manganese Steel	American Institute of Mining Engineers	1893
15	Steel and Iron Alloys	Institution of Civil Engineers	1897
17	Alloys of Iron & Nickel	Institution of Civil Engineers	1899
24	Alloys of Iron, Manganese and Nickel	Institution of Civil Engineers	1903
25	Alloys of Iron & Tungsten	Iron and Steel Institute	1903
26	Iron and Steel Alloys,* including— Iron and Cobalt, Iron and Copper, Iron and Titanium, Iron and Molybdenum, Iron and Vanadium	*Iron and Steel Metallurgist and Metallographist*	1904
27	Alloys of Iron (Researches on the Physical Properties of an Extensive Series)*	Royal Dublin Society	1904
31	On the Properties of a Series of Iron-Nickel-Manganese-Carbon Alloys.* (Seventh Report of the Alloys Research Committee)	Institution of Mechanical Engineers	1905

* Joint paper with others.

(2) ALLOYS OF IRON AND STEEL—Contd.
(Other than Manganese)

No.	Title.	Where read or published.	Year.
70	The Chemical and Mechanical Relations of Iron, Cobalt, and Carbon	Institution of Mechanical Engineers	1915
76	Alloys of Iron and Molybdenum	Institution of Mechanical Engineers	1915
147	Development of Alloy Steel	Empire Mining and Metallurgical Congress	1924

(3) SOUND STEEL

No.	Title.	Where read or published.	Year.
41	Expériences sur la Ségrégation dans les Lingots d'Acier	*Revue de Métallurgie*	1910
51	The Production of sound Steel	*Iron Age*	1912
53	On a New Method of Revealing Segregation in Steel Ingots	Iron and Steel Institute	1912
54	Method of Producing Sound Ingots	Iron and Steel Institute	1912
55	Plant for Producing Sound Steel Ingots	American Institute of Mining Engineers	1913
56	Méthode pour produire des Lingots d'Acier Sains et Décéler la Ségrégation dans les Lingots d'Acier	*Revue de Métallurgie*	1913
57	Nouvelle Méthode pour Décéler la Ségrégation dans les Lingots d'Acier	*Revue de Métallurgie*	1913
63	Sound Ingots	American Institute of Mining Engineers	1914
67	Sound Steel Ingots and Rails*	American Institute of Mining Engineers	1915
68	Sound Steel for Rails and Structural Purposes	Franklin Institute	1915
72	Sound Steel Ingots and Rails*	Iron and Steel Institute	1915
73	Sound Steel for Rails and Structural Purposes. (Second Communication)	Franklin Institute	1915

* Joint paper with others.

(3b) STEEL MAKING

No.	Title.	Where read or published.	Year.
154	Physical Chemistry in Steel Making	Faraday Society	1925

(4) MECHANICAL TESTS

No.	Title.	Where read or published.	Year.
98	Impact Tests on Steel	Steel Treating Research Club	1917
113	Brinell and Scratch Tests for Steel*	Institution of Mechanical Engineers	1919
127	Shock Tests and Their Standardization*	Institution of Civil Engineers	1920
144	Importance of Special Alloy Steels in Industry	*Testing* (Jan.)	1924

(5) HARDNESS AND HARDENING

No.	Title.	Where read or published.	Year.
40	A Research on the Hardening of Carbon and Low Tungsten Tool Steels*	Institution of Mechanical Engineers	1910
66	Address as Chairman at discussion on "The Hardening of Metals"	Faraday Society	1914
90	Contribution to Discussion on Hardness Tests Research Committee Report	Institution of Mechanical Engineers	1916
94	Spontaneous Generation of Heat in Recently Hardened Steel*	Royal Society	1917
103	Further Experiments on the Spontaneous Generation of Heat in Recently Hardened Steel*	Royal Society	1918
105	Contribution on Hardness	Institution of Mechanical Engineers	1918
113	Brinell and Scratch Tests for Steel*	Institution of Mechanical Engineers	1919
127	Shock Tests and Their Standardization*	Institution of Civil Engineers	1920

* Joint paper with others.

(6) ELECTRICAL AND MAGNETIC PROPERTIES

No.	*Title.*	*Where read or published.*	*Year.*
21	On the Electrical Conductivity and Magnetic Permeability of Iron*	Royal Dublin Society	1900
22	Researches on the Electrical Conductivity and Magnetic Properties of upwards of One Hundred Different Alloys of Iron*	Institution of Electrical Engineers	1902
23	On the Magnetic Properties of an Extensive Series of Alloys of Iron*	Royal Dublin Society	1902
32	On the Magnetic Qualities of Some Alloys not Containing Iron*	Royal Society	1905
39	The Magnetic Properties of Iron and Its Alloys in Intense Fields*	Institution of Electrical Engineers	1910
49	The Magnetic Properties of Alloys. (Contribution to the International Discussion)	Faraday Society	1912
60	Research with Regard to the Non-Magnetic and Magnetic Conditions of Manganese Steel*	American Institute of Mining Engineers	1914
64	The Magnetic and Mechanical Properties of Manganese Steel*	Iron and Steel Institute	1914
92	The Corrosion and Electrical Properties of Steels*	Royal Society	1916
99	A Contribution to the Study of the Magnetic Properties of Manganese, and of Some Special Manganese Steels*	Royal Society	1917
126	The Magnetic Mechanical Analysis of Manganese Steel*	Royal Society	1920
128	On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese*	Royal Society	1921

* Joint paper with others.

(7) PRODUCTION OF MAGNETIC ALLOYS FROM NON-MAGNETIC METALS

No.	*Title.*	*Where read or published.*	*Year*
28	Magnetic Alloys from Non-Magnetic Metals	British Association	1904
29	Production of Magnetic Alloys from Non-Magnetic Metals	*Chemical News*	1904

(8) CORROSION OF IRON AND STEEL

No.	*Title.*	*Where read or published.*	*Year.*
77	Address as President, entitled "Corrosion of Steel Alloys," at Discussion on "Corrosion of Metals"	Faraday Society	1915
82	The Influence of Carbon and Manganese upon the Corrosion of Iron and Steel*	Iron and Steel Institute	1916
92	The Corrosion and Electrical Properties of Steels*	Royal Society	1916
133	Corrosion of Ferrous Metals	Institution of Civil Engineers	1922
135	Corrosion of Iron and Steel	Royal Society	1922
139	Corrosion of Iron & Steel	Int. Navigation Congress,	1923
142	Corrosion of Ferrous and Non-Ferrous Metals	Birmingham Municipal Technical School	1923
152	Address as Chairman at Discussion on "Protective Paint Coatings"	Joint Meeting of Society of Chemical Industry and Oil and Colour Chemists' Association	1925

(9) THE EFFECT OF LOW TEMPERATURES UPON IRON, STEEL, AND ALLOY STEELS

No.	*Title.*	*Where read or published.*	*Year.*
30	On the Effect of Liquid Air Temperatures on the Mechanical and Other Properties of Iron and its Alloys*	Royal Society	1904

* Joint paper with others.

(9) THE EFFECT OF LOW TEMPERATURES UPON IRON, STEEL, AND ALLOY STEELS—Contd.

No.	Title.	Where read or published.	Year.
34	Experiments Relating to the Effect on Mechanical and Other Properties of Iron and its Alloys Produced by Liquid Air Temperatures	Iron and Steel Institute	1905
35	Effet de la Température de l'Air liquide sur les Propriétés mécaniques et autres du Fer et de ses Alliages	Congrès International des Mines, de la Métallurgie, de la Mécanique et de la Géologie Appliquées (Section de Métallurgie)	1905
128	On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese*	Royal Society	1921
129	On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese*	Physical Laboratory of the University of Leiden	1921

(10) METALLOGRAPHY

No.	Title.	Where read or published.	Year.
116	Address as President at General Discussion on " The Microscope "	Faraday Society	1920
117	Photomicrographs of Steel and Iron Sections at High Magnification*	Faraday Society	1920
119	The Great Work of Sorby	Faraday Society	1920
143	Address as Chairman at Meeting on Industrial Application of the Microscope	Royal Microscopical Society	1924
153	Development of the Use of the Microscope in Steel Works.	Royal Microscopical Society (Sheffield Conference)	1925

* Joint paper with others.

(11) PYROMETERS

No.	Title.	Where read or published.	Year.
71	Address as Chairman at Discussion on Mr. Chas. R. Darling's Paper, "Recent Progress in Pyrometry"	Royal Society of Arts	1915
100	Address at General Discussion on "Pyrometers and Pyrometry"	Faraday Society	1917

(12) X-RAY EXAMINATION OF IRON, STEEL, AND OTHER MATERIALS

No.	Title.	Where read or published.	Year.
109	Address as President at General Discussion on the Examination of Materials by X-Rays	Faraday Society and Röntgen Society	1919
110	Testing the Absorption Power of Different Steels under X-Rays*	Faraday Society	1919
111	X-Ray Examination as Applied to the Metallurgy of Steel*	Faraday Society	1919
112	Radiographic Examination of Carbon Electrodes Used in Electric Steel-making Furnaces*	Faraday Society	1919

(13) EARLY HISTORY OF CRUCIBLE STEEL

No.	Title.	Where read or published.	Year.
10	Huntsman, the Inventor of Crucible Steel	American Institute of Mining Engineers	1893
12	The Early History of Crucible Steel	Iron and Steel Institute	1894

* Joint paper with others.

(14) ANCIENT IRON AND STEEL

No.	*Title.*	*Where read or published.*	*Year.*
44	Sinhalese Iron and Steel of Ancient Origin	Royal Society	1911
45	Sinhalese Iron and Steel of Ancient Origin	Iron and Steel Institute	1911
46	Abstract from Paper on "Sinhalese Iron and Steel of Ancient Origin"	*Nature*	1912
47	Abstract from Paper on "Sinhalese Iron and Steel of Ancient Origin," with Addendum regarding Delhi Pillar	Royal Society	1912
48	Analysis of the Iron Pillar, made about A.D. 300 at Delhi	*Engineering*	1912

(15) FUEL

No.	*Title.*	*Where read or published.*	*Year.*
101	Presidential Address	Society of British Gas Industries	1918
114	Report on Fuel Economy and Consumption in the Manufacture of Iron and Steel*	Iron and Steel Institute	1919
115	Fuel Control in Metallurgical Furnaces*	Iron and Steel Institute	1919
120	Address as Chairman at Mr. H. M. Thornton's Lecture on "Gas in Relation to Industrial Production"	Royal Society of Arts	1920
148	Works Problems and Methods in Fuel Economy	Empire Mining and Metallurgical Congress	1924
149	Fuel Economy and the Measurement of High Temperatures	World Power Conference	1924

* Joint paper with others.

(16) ADDRESSES—PRESIDENTIAL

No.	Title.	Where read or published.	Year.
11	Presidential Address	Sheffield Society of Metallurgists and Engineers	1893
33	Presidential Address	Iron and Steel Institute	1905
37	Presidential Address	Iron and Steel Institute: Joint Meeting with American Institute of Mining Engineers	1906
65	Presidential Address: ("Advances in the Metallurgy of Iron and Steel")	Faraday Society	1914
101	Presidential Address	Society of British Gas Industries	1918
102	Presidential Address to Society of British Gas Industries	*Gas*	1918
124	Presidential Address	British Commercial Gas Association	1920

(17) ADDRESSES—OTHER THAN PRESIDENTIAL

No.	Title.	Where read or published.	Year.
19	Address as Master Cutler to the Cutlers' Co.	Sheffield Press	1899
20	Address and Distribution of Prizes to Students at Technical Dept. of Sheffield University College	Sheffield Press	1899
36	"James Forrest" Lecture on "Unsolved Problems in Metallurgy"	Institution of Civil Engineers	1906
38	Address to Students at Columbia University, New York	*Iron Age*	1907
43	Address at Sheffield University on the Conferment of Honorary Degree of Doctor of Metallurgy	Sheffield Press	1911
59	The Progress of the Metallurgy of Iron and Steel	American Institute of Mining Engineers	1914
69	History of the Metallurgy of Iron and Steel	Institution of Mechanical Engineers	1915

(17) ADDRESSES—OTHER THAN PRESIDENTIAL—Contd.

No.	*Title.*	*Where read or published.*	*Year.*
71	Address as Chairman at Discussion on Mr. Chas. R. Darling's Paper, "Recent Progress in Pyrometry"	Royal Society of Arts	1915
74	Address as Chairman at Discussion on "The Transformations of Iron"	Faraday Society	1915
77	Address as President, entitled "Corrosion of Steel Alloys" at Discussion on "Corrosion of Metals"	Faraday Society	1915
80	Address as Chairman at Discussion on "Methods and Appliances for the Attainment of High Temperatures in the Laboratory"	Faraday Society	1916
81	Address as Chairman at Dr. Rosenhain's Lecture on "The Making of a Big Gun"	Faraday Society	1916
83	Address as Chairman at Annual Banquet of London Association of Foremen Engineers	*The Managing Engineer*	1916
84	Address as Chairman of Ferrous Section of Special Committee of Advisory Council	Board of Education	1916
87	Address as Chairman at Discussion on "Refractories"	Faraday Society	1916
95	Address as Chairman at Discussion on "The Training and Work of the Engineering Chemist"	Faraday Society	1917
104	Address as Chairman at General Discussion on "The Co-ordination of Scientific Publication"	Faraday Society	1918
106	Address as Chairman at General Discussion on "The Occlusion of Gases by Metals"	Faraday Society	1918

(17) ADDRESSES—OTHER THAN PRESIDENTIAL—Contd.

No.	*Title.*	*Where read or published.*	*Year.*
107	Address as Chairman at General Bagnall Wild's Lecture on "Aircraft Steels"	Royal Aeronautical Society	1918
108	Address as Chairman at General Discussion on "Electric Welding"	Royal Society of Arts	1919
109	Address as President at General Discussion on "The Examination of Materials by X-Rays"	Faraday Society and Röntgen Society	1919
116	Address as President at General Discussion on "The Microscope"	Faraday Society	1920
118	The Work of the Faraday Society and Michael Faraday	Faraday Society	1920
120	Address as Chairman at Mr. H. M. Thornton's Lecture on "Gas in Relation to Industrial Production"	Royal Society of Arts	1920
121	Address as Chairman at General Discussion on "Basic Slags"	Faraday Society	1920
122	Address on the Work of the Nitrogen Products Committee	Faraday Society	1920
123	Address at Mr. M. S. Birkett's Lecture on "The Iron and Steel Trades During War"	Royal Statistical Society	1920
125	Address as Chairman at General Discussion on "Physics and Chemistry of Colloids and Their Bearing on Industrial Questions"	Faraday Society	1920
130	Address of Thanks on the occasion of the Award of the John Fritz Medal	Institution of Civil Engineers	1921
131	Address at Engineering Conference as Chairman of Section IV, "Mining and Metallurgy"	Institution of Civil Engineers	1921
132	The Work and Position of the Metallurgical Chemist	Sheffield Association of Metallurgists and Metallurgical Chemists	1921

(17) ADDRESSES—OTHER THAN PRESIDENTIAL—Contd.

No.	Title.	Where read or published.	Year.
134	Metallurgy of Iron and Steel	Pitman's Technical Primer Series	1922
136	Advances in the Metallurgy of Iron and Steel	Cambridge University Engineering Society	1923
137	Special Steels	Pitman's Technical Primer Series	1923
141	History and Progress of Metallurgical Science	Birmingham University Metallurgical Society	1923
146	Advances in Metallurgy of Iron and Steel	Leicester Association of Engineers	1924
151	Metallurgy and its Influence on Modern Progress	Oxford University Junior Scientific Club	1925

(18) THE PROGRESS OF METALLURGY

No.	Title.	Where read or published.	Year.
42	Les Progrès de la Métallurgie	*Le Génie Civil*	1910
50	The World's Progress in Metallurgy	*Iron Age*	1912

(19) SOME OF THE CONTRIBUTIONS TO DISCUSSIONS

No.	Title.	Where read or published.	Year.
62	Contribution to Discussion on Mr. W. S. Potter's Paper on "Manganese Steel"	American Institute of Mining Engineers	1914
70	Contribution to Discussion on Dr. J. O. Arnold's Paper, "The Chemical and Mechanical Relations of Iron, Cobalt, and Carbon"	Institution of Mechanical Engineers	1915
75	Contribution to the Discussion of Dr. Dugald Clerk's Address, "English and German Methods Contrasted"	Royal Society of Arts	1915
78	Contribution to the Discussion on Sir Frank Heath's Paper, "The Organization of Scientific Research"	Royal Society of Arts	1919

(19) SOME OF THE CONTRIBUTIONS TO DISCUSSIONS—Contd.

No.	*Title.*	*Where read or published.*	*Year.*
79	Contribution, " Britain's Part in the Trade War —Scientific Research "	*Daily Telegraph* (London)	1916
93	Contribution to Discussion on " The Mineral Resources of the British Empire "	Society of Engineers	1916
96	Contribution to Discussion on Sir Wm. Beardmore and Mr. H. H. Ashdown's Papers on " Heat Treatment of Steel Forgings "	Institution of Mechanical Engineers	1917
97	Contribution to Discussion on Mr. Edgar Crammond's Lecture, " Foreign Trade in Relation to the Investment of Capital Abroad "	Institution of Civil Engineers	1917
150	Contribution to Discussion on Dr. Rosenhain's paper " Hardening of Steel "	Iron and Steel Institute	1924
155	Contribution to Discussion on Professor H. J. Goudie's paper " The Internal Combustion Turbine "	Institution of Engineers and Shipbuilders in Scotland	1925

(20) EDUCATION

No.	*Title.*	*Where read or published.*	*Year.*
88	Suggestions with Regard to the Co-ordination and Organization of Scientific and Technical Societies	Board of Scientific Societies	1916
95	Address as Chairman at Discussion on " The Training and Work of the Engineering Chemist "	Faraday Society	1917

(21) GENERAL

No.	*Title.*	*Where read or published.*	*Year.*
8	Notes on the Chicago Exhibition	Iron and Steel Institute	1893
14	The Production of Iron by a new Process	Iron and Steel Institute	1895
16	Foreign Technical Progress	Iron and Steel Institute	1897
18	The Influence of Casting Temperature upon Steel	Institution of Civil Engineers	1899
52	The World's Production of Pig Iron	*The Times*	1912
85	Remarks to Sir Ray Lankester regarding "The Neglect of Science"	Report of Committee on "The Neglect of Science"	1916
86	The Training of Captains of Industry	*Iron and Coal Trades Review*	1916
89	Science and Trade	*Daily Telegraph* (London)	1916
91	Reply to *The New Age* Industrial Symposium Question	*The New Age*	1916

LIST OF SYMPOSIA OF THE FARADAY SOCIETY

(*a*) 1907–1914

No.	*Date of Discussion.*	*Vol.*	*Title.*	*No. Papers Read.*	*No. of Pages.*
1	1907, Jan.	III	Osmotic Pressure	4	30
2	1907, June	III	Hydrates in Solution	4	40
3	1910, April	VI	The Constitution of Water	5	50
4	1911, May	VII	High Temperature Work	5	40
5	1912, April	VIII	The Magnetic Properties of Alloys	12	130
6	1913, Mar.	IX	Colloids and Their Viscosity	5	80
7	1913, April	IX	The Corrosion of Iron and Steel (Manchester)	4	30
8	1913, Nov.	IX	The Passivity of Metals	8	90
9	1914, Mar.	X	Optical Rotatory Power	11	100
				58	590

LIST OF SYMPOSIA OF THE FARADAY SOCIETY—Contd.

(*b*) During Sir Robert Hadfield's Presidency, 1914–1920

No.	*Date of Discussion.*	*Vol.*	*Title.*	*No. Papers Read.*	*No. of Pages.*
10	1914, Nov.	X	The Hardening of Metals	10	100
11	1915, Oct.	XI	The Transformation of Pure Iron	3	40
12	1915, Dec.	XI	The Corrosion of Metals	8	120
13	1916, Mar.	XII	Methods and Appliances for the Attainment of High Temperatures in the Laboratory	2	10
14	1916, Nov.	XII	Refractory Materials	20	210
15	1917, Mar.	XIII	The Training and Work of the Chemical Engineer	6	60
16	1917, May	XIII	Osmotic Pressure	5	70
17	1917, Nov.	XIII	Pyrometers and Pyrometry	19	180
18	1918, Jan.	XIV	The Setting of Cements and Plasters	10	70
19	1918, Feb.	XIV	Electric Furnaces (Manc'st'r)	3	50
20	1918, May	XIV	Co-ordination of Scientific Publication	1	30
21	1918, Nov.	XIV	The Occlusion of Gases by Metals	9	100
22	1919, Jan.	XV	The Present Position of the Theory of Ionization	15	180
23	1919, April	XV	Examination of Materials by X-Rays	15	150
24	1920, Jan.	XVI	The Microscope	50	260
25	1920, Mar.	XVI	Basic Slags	10	50
26	1920, Oct.	XVI	Physics and Chemistry of Colloids and Their Bearing on Industrial Questions	20	200
				206	1880

(*c*) 1920–1922

27	1920, Nov.	XVI	Electrodeposition and Electroplating	12	67
28	1921, April	XVII	The Failure of Metals under Internal and Prolonged Stress	20	220
29	1921, May	XVII	Physico-Chemical Problems relating to the Soil	22	119
30	1921, Feb.	XVII	Capillarity	5	23
31	1921, Sept.	XVII	Catalysis with Special Reference to Newer Theories of Chemical Action	15	202
32	1922, Mar.	XVIII	Some Properties of Powders	10	60
33	1922, Oct.		The Generation and Utilization of Cold	11	273
				95	964

APPENDIX IV

ILLUSTRATING THE RAMIFICATIONS OF INTERNATIONAL CO-OPERATION.

The subjoined list includes the names of some of the famous scientists, physicists, chemists, engineers, and others with whom the author has been in touch, personally or by correspondence, during the years 1878–1924. To most of these he has supplied specimens, particulars, and technical information relating to his various steels, also other metallurgical data of scientific and technical character.

GREAT BRITAIN:

Abel, Sir F., F.R.S.
Adamson, D. (P.P.I.S.I.)
Airedale, Lord, D.Sc. (P.P.I.S.I.)
Aitchison, Dr. Leslie.
Allen, W. D., F.I.C.
Andrews, T., F.R.S.
Armstrong, Lord, F.R.S. (P.P.I.C.E.)
Armstrong, Professor H. E., F.R.S.
Arnold, Dr. J. O., F.R.S.
Aspinall, Sir John (P.P.I.C.E.)
Balfour, Sir Arthur.
Bagnall-Wild, Gen. R. K.
Baker, Sir Benjamin, F.R.S. (P.P.I.C.E.)
Baker, William, F.I.C.
Barnaby, Sir F.
Barnaby, Sir Nathaniel.
Barrett, Sir William, F.R.S.
Barry, Sir John Wolfe, F.R.S. (P.P.I.C.E.)
Bauerman, Professor.
Beilby, Sir G. T., F.R.S.
Bell, Sir Lowthian, F.R.S.
Bell, Sir Hugh, (P.P.I.S.I.)
Bessemer, Sir Henry, F.R.S.
Bottomley, Prof. J. T., F.R.S.
Bragg, Sir W., F.R.S.
Bragg, W. L., F.R.S.
Bramwell, Sir F., F.R.S.(P.P.I.C.E.)
Brearley, H.
Brown, Professor W.
Bruce, Sir George (P.P.I.C.E.)
Callendar, Prof. H. L., F.R.S.
Carpenter, Dr. H. C. H., F.R.S.
Churchward, G. J., M.Inst.C.E.
Clerk, Sir Dugald, F.R.S.
Cooper, A., LL.D. (P.P.I.S.I.)
Crompton, Colonel R. E. (P.P.I.C.E.)
Crookes, Sir William, F.R.S.
Dalby, Professor W. E., F.R.S.
Dale, Sir David (P.P.I.S.I.)
Darby, J. H.
Desch, Dr. C. H., F.R.S.
Devonshire, Duke of, K.G.
Dewar, Sir James, F.R.S.
Donaldson, Sir Frederick.
Donnan, Prof. F. G., F.R.S.
Ellis, J. D.
Ellis, Sir William (P.P.I.S.I.)
Elliot, T. G., F.R.S.
Ewing, Sir Alfred, F.R.S.
Fleming, Prof. J. A., F.R.S.
Friend, Dr. J. Newton.
Glazebrook, Sir R. T., F.R.S.
Gilchrist, P. C., F.R.S.
Gowland, Professor W., F.R.S.
Greenwood, Professor W. H.
Goodman, John
Hatschek, E., A.M.I.Mech.E., F.Inst.P.

GREAT BRITAIN—Contd.

Harbord, F. W., C.B.E., A.R.S.M.
Harker, Dr. J. A.
Hatfield, Dr. W. H.
Hele-Shaw, Dr. H. S., F.R.S.
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Weiss, Professor Pierre.
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Woltjer, Dr. H. R.

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Ehrensberger, Dr. E.
Heyn, Professor E.
Ledebur, A.
Mars, G.
Martens, A.
Muller, Professor.
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APPENDIX V

TYPES AND METHODS OF RESEARCH

Through which Discovery and Invention may be attained, as described by the late Dr. G. Gore, F.R.S., in his book, *The Art of Scientific Discovery.*

In view of the great importance and valuable nature of Gore's advice, since it applies just as much to-day as when first given, the following extracts are quoted " On the General conditions and methods of research in Physics and Chemistry " as set forth in his admirable book *The Art of Scientific Discovery.*

Gore says that many scientific men hesitate to undertake original research from a fear of the great difficulty of the task and of repeating experiments which others have already made, and also because they do not know how to select suitable subjects ; and, as one of the most effectual preliminary conditions of ensuring success in research is a thorough study of the general and special methods and conditions of discovery, it is hoped that such persons will be induced to attempt original investigation by the aid of the suggestions contained in this book.

Although men have during all modern time made discoveries in physics and chemistry, and many eminent investigators have occupied and are still occupying a large portion of their lives in original scientific research, the conditions of success and failure in the pursuit of original scientific inquiry and the methods employed in making discoveries remain for the most part unknown to ordinary persons.

In nearly all cases investigators, from some cause or other, have not troubled themselves to describe the actual circumstances which gave rise to their discoveries, and have thus failed to leave behind them the ladder by which they ascended, and by which others might, to some extent at least, have been assisted in the pursuit of similar objects. Faraday, and particularly Kepler, did, however, leave an account of a few of the failures as well as the successes of their researches.

Whilst I do not forget Dr. Whewell's assertion that, speaking with strictness, an "Art of Discovery" is not possible; that we can give no rules for the pursuit of truth which shall be universally and peremptorily applicable; and that the helps which we can offer to the inquirer in such cases are limited and precarious, I share his hope that aids may be pointed out which are neither worthless nor uninstructive.

To some the very proposal to write a book on such a subject may appear presumptuous; and even among scientific investigators there are those who consider that the methods of discovery are incommunicable. But original scientific research is not a supernatural operation. If it were, it would not be possible to make discoveries by means of our natural faculties, nor to communicate them by ordinary means. It is a natural process, and being such, it must have laws according to which it operates. It is effected by means of our mental powers, and is therefore subject to the rules of mental action, and is communicable by ordinary natural methods. It is also being reduced, as knowledge advances, to rules of action, and will in time become one of the noblest of all intellectual employments. It is well known that by obeying the laws of Nature we learn how to employ them; and by studying the principles of science, and the action of the human mind in original research, we may reasonably expect to learn the essential conditions upon which success in scientific discovery depends.

In Gore's book, Chapter II deals with Special Methods of Discovery, Personal Preparation for Research; Chapter XII with Actual Working in Original Scientific Research, General Conditions of Scientific Research; and Chapter XIV, General view and basis of Scientific Research.

The following Table represented the types of Research and methods by which discovery and invention may be attained:

1. Aid to Analogy.
2. Hypotheses.
3. Analysis and Synthesis.
4. Application of—
    (a) Electricity to bodies.
    (b) Heat to substances.
5. Asking questions and testing such questions.
6. Assumptions that—
    (a) There is certainty of all the great principles of science.

(*b*) Complete homologous series exist.
(*c*) Converse principles of action exist.
(*d*) Certain general statements which are true of one force or substance are true to some extent of others.

7. Combined action of many observers.
8. Comparisons of—
    (*a*) Facts, and collecting similar ones.
    (*b*) Collections of facts with each other.
    (*c*) The orders of collections of facts.
    (*d*) Facts with hypotheses.
9. Deducting process.
10. Employment of new or improved means of observation.
11. Examination of—
    (*a*) Common but neglected substances.
    (*b*) Effects of forces on substances.
    (*c*) Effects of contact on substances.
    (*d*) Effects of extreme degrees of force.
    (*e*) Extreme or conspicuous instances.
    (*f*) Influence of time upon phenomena.
    (*g*) Neglected truths and hypotheses.
    (*h*) Peculiar minerals.
    (*i*) Unexpected truths.
    (*j*) Rare substances.
    (*k*) Residue phenomena.
    (*l*) Residues of manufacture.
    (*m*) The ashes of rare plants and animals.
12. Extension of—
    (*a*) The researches of others.
    (*b*) The researches of neglected parts of science.
13. Inductive process.
14. Investigations of—
    (*a*) Exceptional cases.
    (*b*) Unexpected phenomena.
    (*c*) Classification unexplained.
15. Means of—
    (*a*) Converse experiments.
    (*b*) Hypotheses.
    (*c*) "Homologous Series."
    (*d*) Instruments of great power.
    (*e*) Improved methods of intellectual operation.
    (*f*) Measurements.

(*g*) The method of curves.
(*h*) The method of least squares.
(*i*) The method of means.
(*j*) The method of residues.
(*k*) New instruments.
(*l*) Modes of observation.
(*m*) Observations.
(*n*) More intelligent and acute observation.
(*o*) Additional observations by known methods.
(*p*) Periodic functions.
(*q*) More refined methods of working.
(*r*) Repetition of experiments.

16. Simple comparisons of facts of phenomena.
17. Search for—
    (*a*) So-called "impossible" things.
    (*b*) One thing and finding another.
18. Subjecting series of forces or substances to new conditions.
19. Use of—
    (*a*) Known instruments or forces in a new way.
    (*b*) Improved instruments.
    (*c*) More powerful instruments.
    (*d*) Causes by the methods of averages.
    (*e*) Coincidences.
20. Conditions of—
    (*a*) Scientific Discovery
    (*b*) Determination of the nature of a discovery contrasted with barren reasoning.
21. Dependence of discovery upon art of exceptional instances.
22. Fundamental laws of discovery.

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